JÖNKÖPING UNIVERSITY
School of Engineering

Master Thesis

Development, Validation and Implementation of Universal Testing Machine

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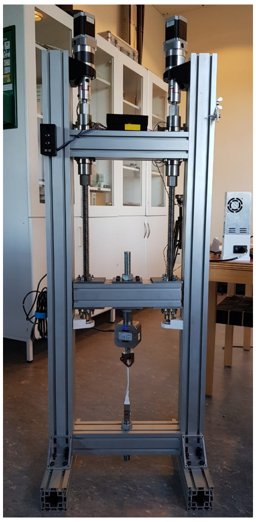

Jönköping University
School of Engineering
Department of Product Development • June 2019

This thesis has been carried out at the School of Engineering, Jönköping University, in the subject area Mechanical Engineering. The authors answer themselves for opinions, conclusions and results.

Examiner:	-
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Scope:	30 credits
Date:	2020-08-13

Abstract

The thesis paper will be covering the grounds of what, how and why a Universal Testing Machine is used, an alternative to the generic Universal Testing Machine designs and how it is built. The primary objective of this thesis work is to design and build a Universal Testing Machine which can handle a load up to 10kN for polymer materials which is cost effective and modular. The operating system and electronic components are open-source leaving room for further development and compression test.

The mechanical properties of material can be measured through tensile test. It gives the the characteristic of tensile strength, yield strength, modulus of elasticity, ductility, resilience, and toughness. The thesis paper covers the use of real time image processing for calculating and plotting of a stress strain curve. It also covers the implementation of open source code, using a MATLAB user interface to control, analyse and compile the results of tests done using the new machine. These results have been compared to values obtained from a standard Universal Testing machine and thus validated.

As the machine is modular, the parts can be swapped with better components that fits the requirement, leaving the possibility for easy upgrades in the future.

Acknowledgments

We would like to express our sincere gratitude towards Jönköping School of Engineering, Assistant Professor Mirza Cenanovic, Jönköping University, Assistant Professor David Samvin, Jönköping University Jönköping, for providing us with the incredible opportunity to this project work and for their excellent guidance during our work. We would also like to thank Jacob Steggo, Development Engineer, Jönköping University, and Mr.Esbjorn Ollas, Laboratory Technician, Jönköping University for their valuable support and assistance during various stages during the construction and testing of UTM. Our two year Master's program is coming to an end and we would like to thank each and every person who has helped or supported us during our journey. Thank you.

- Stephen Jose Mathew & Vijay Francis

Contents

1 Introduction

The selection of a material to make a product is done based on the various characteristics and properties exhibited by the material in various conditions, forces and environment. To quantify the material property for a person who is not too familiar with it, a standard testing method is brought into play and for this a Universal Testing Machine is used. The conventional UTM machines built by companies are not exactly cost effective or user friendly. And at times high capacity machines do not register low measurements values [20].

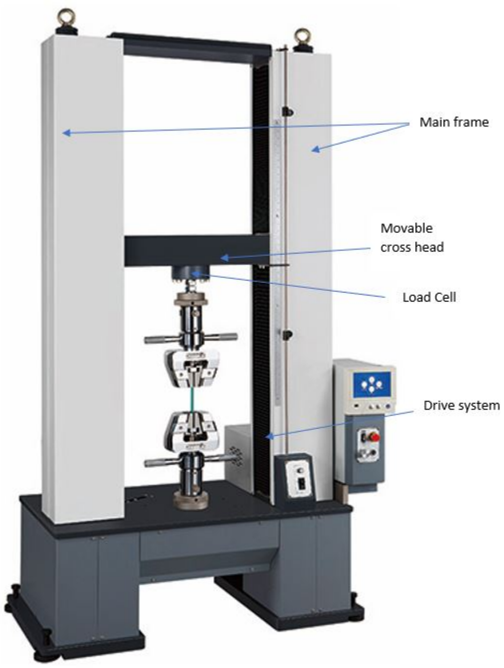

Figure 1: Universal testing machine and its parts

More over most of the old generation UTM's use hydraulic or pneumatic drive systems and controlled using old and outdated interface and software, making them hard to be integrated to any new systems or giving them a much needed upgrade. These machines use an extensometer to measure the change in length. The conventional UTM's are extremely bulky, so they take up a considerable amount of space and cannot be moved or relocated once they are fixed and calibrated for a position.

The objective of this thesis project is to develop, validate and deploy an open source, universal testing machine that consists of affordable and readily accessible parts that can either be 3D printed or can be easily machined in house for the university. The steps involved would include CAD designing, manufacturing and assembling of parts, PCB coding, optical imagery using a high resolution camera, followed by controlling and processing by a MATLAB Graphical User Interface.

2 Background Information

Tensile testing, is a fundamental materials science test in which a test piece of a material is subjected to a controlled tension until failure. The results from the test is commonly used to select a material for an application depending on the requirements and to predict how a material will perform or behave under other types of force. The properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction. The following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics. Uni-axial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials. For an-isotropic materials, such as composite materials and textiles, bi-axial tensile testing is required. So to carry out such type of testing Universal Testing Machines (UTM) are used to carry out tensile test, compression & bending test.

The testing machine is designed to determine the stress strain curves of polymer materials such as polymers and particularly metallic films deposited onto polymeric substrates. Different methods have been proposed to investigate the mechanical properties of these thin materials. As is shown in Figure 1, the testing machine is composed of five main parts: i) the main frame, ii) the drive system, iii) the movable cross-head, iv) the load cell, and v) the digital indicator.

JTH needs a dedicated universal testing machine for mechanical testing of polymers and fiber reinforced polymers. The current testing machines are mainly used for metallic materials and require time to set up for polymer testing. Another issue is that the current machine is often in use, therefore another machine is needed to allow for parallel testing. The current machine uses commercial software and does not allow for easy updates of hardware or software. The objective of this project is to develop and validate an open source, universal testing machine that consists of cheap and readily accessible parts where many parts are 3D printed and/or easily machined in house. The software will also be developed in house and kept on public repository's as open source.

The proposed master thesis is to build a robust and accurate Universal testing machine for polymer samples at a relatively low budget, initially for tensile and compression tests. The proposed design is modular, extremely cost efficient and has a very low initial investment to make. And since the interface and control system are being designed based on open-source software, future upgrading can be done with ease. For measuring the load on a sample (compression), a load cell is used and for strain an optical method is used (camera with a physical extension meter and laser). The test machine will have a 10 kN load cell with a factor of safety of 1.5. For the tensile testing the test piece will be marked on the surface and a high resolution camera will be used to capture the images at specific time intervals, these images will be analysed in real time using MATLAB to get the stress strain curve.

One of the major flaws encountered while using the commercial machine was that the control program used to run it based on outdated software and coding with no technical support or prospect for upgrade. The current interface was made using programming languages like C++, Java Scrips from back in 2000-2001 which can be supported by Windows Xp which was made on Windows NT Kernel which is a 1990's platform. And since it is so ancient the UI is not supported by any modern operating system and so needs a dedicated system with older drivers to run on. This severely limits the capability of analysis as modern analysis programs cannot be integrated or run along side it. And it doesn't have any advanced option to do an in-depth comparison results or to export the obtained results and graph to a different platform or format. Moreover the camera system used is rudimentary and can only track specific section of a test piece and not as a whole.

Since the machine is specifically for polymers, the test pieces would have a limitation as to have specific dimensions. The test piece standards can be seen in the picture below which is from a research paper [20][4].

The background data required for the project work was collected based mostly on Grey Literature provided on web sites like github[1] and Youtube channel CNC Kitchen[2], design and data provided by them have been extensively analysed and modified to meet the requirements on. The design inspiration was taken from a model built by Stefan rom CNC kitchen[10].

[1]https://github.com/CNCKitchen/Open-Pull

[2]https://www.youtube.com/watch?v=uvn-J8CbtzM

2.1 Objective

The primary Objective is to design and manufacture a cost effective and modular tensile testing machine with up-gradable option using relatively low cost and readily available materials in workshop. The machine would be run using open source code with a Graphical User Interface made using MATLAB.

The other objectives to keep in mind while designing the machine:

1) Camera : instead of conventional measuring instruments like extensometer the new machine will be using a optical instrument(a high resolution camera) to measure the change in length using real time image processing technology. This actually gives a slight advantage for the new machine over the old one as a image tracking technology can measure and detect even minute change in length.

2) Image analysis : The acquired images should be analysed and strain computed.

3) Graph plotting : The change in length is calculated by MATLAB from the frames acquired and the stress values from the load cell are compiled to for plot the stress vs strain graph.

4) Graphical user interface (GUI) : A GUI made using MATLAB will be used to control the tests and display results.

All the designs,blueprints, building plans, electrical circuitry diagrams, codes and GUI for system control would be uploaded to “Github.com” making it available for the public to modify and improve upon.

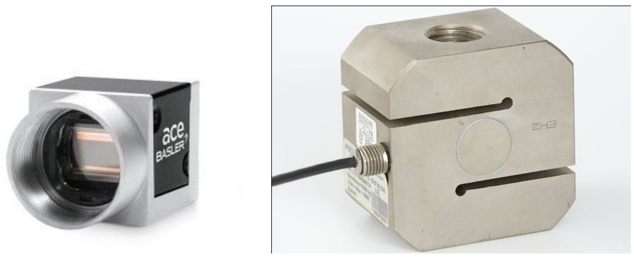

Figure 2: Camera and load cell used

3 Problem Description

The UTM that is currently in JTH is which has a capacity of 100kN and operates using an electrical drive mechanism. For normal polymers this capacity is too high and in many cases wont even register any change in load application. When such cases occur huge changes in settings is required to get an accurate reading and correct graph. There has been instances where 3D printed samples were tested on the machine and the values obtained were either too low or highly fluctuating in general. The UTM uses a wedge clamp mechanism which is self centering but has a tendency to crush delicate polymer test pieces when trying to perform any test. Due to this issue sometimes external grippers are put in place to hold the test-pieces. This call for a new design, at a low investment and modular Universal Testing machine for JTH.

Figure 3: Inspirational Design for the new UTM

4 Research Questions

The two main research questions that needs to be tackled:

1. How to design a low investment and upgrade-able universal testing machine to test polymer samples in compression and tension to get a stress strain curve?
2. How to verify the accuracy of the machine and how well does it perform when compared with a standardized UTM?

5 Theoretical background

The engineering tensile test is also known as tension test which vary widely used for providing the base of the design information on the strength of material and as an acceptance test for the specification of the materials. Tensile tests are very simple, relatively, inexpensive, and fully standardized. Under the pulling type of loading a material, it can be very quickly determined how the material will react to the these type of forces being applied in tension. As the materials are being pulled, its strength and elongation can be found out. A lot about a substance can be learned from tensile testing. As the machine continues to pull on the material until it breaks, a good, complete tensile profile can be obtained. The stress - strain curve shows how the material reacts to the force being applied. In the tension test a specimen is subjected to a continually increasing one directional tensile force while simultaneous observations are made of the elongation of the specimen.

The resulting output from such a test is recorded as load versus displacement/elongation and can be graphically displayed as a load - elongation curve. Load - elongation curve is then converted to engineering-stress versus engineering-strain curve to evaluate the tensile properties of materials. Very often engineering-stress versus engineering-strain curves need to be converted to true-stress versus true-strain curves [20].

The tensile properties that can be obtained from the stress-strain curves are yield strength, tensile strength, fracture strength, percent total elongation, uniform elongation, strain hardening exponent, modulus of resilience, and modulus of toughness. [20]

Types of tensile testing include:

- Adhesion/Bond Strength
- Crimp Joint Pull-off Force
- Peel
- Tear Resistance

The data produced in a tensile test can be used in many ways including:

- To determine batch quality
- To determine consistency in manufacture
- To aid in the design process
- To reduce material costs and achieve lean manufacturing goals
- To ensure compliance with international and industry standards

5.1 Design And Model

In order to manufacture the prototype that is modular, easily transferable and cheap, various aspects and considerations are needed to be made. Use of Computer Aided Design (CAD) model using SOLDWORKS 2019 software can be used to develop a sketch and a 3D assembly for an easy understanding of the model. Calculation of load, right specification for a part used and various other factors are considered as well.

5.1.1 SOLIDWORKS

Solid works software is 3D CAD (Computer Aided Design) and CAE (Computer Aided Engineering) computer program which runs primarily on windows OS. This software has features for designing a 3D model of a design as well as assemble it. Various parts for this projects were designed using this software and which were later 3D printed. This software also provides a Finite Element Analysis (FEA) tool which allows for structural analysis where the 3D model can be analyzed for the provided load and boundary conditions. These features were very helpful for this project as it will be explained later.

5.1.2 MATLAB

MATLAB (an abbreviation of "matrix laboratory") is a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages. MATLAB provides the platform required to program and control the machine to work. It has multiple apps and packages that helps communication among different types of hardware used into a single unit. It also has a Graphical User interface application within the software that allows the programmer to add in User Interface controls(UI controls) and feature which can be used for easy usability for a third party user, with limited understanding of coding in MATLAB.

5.1.3 Hardware

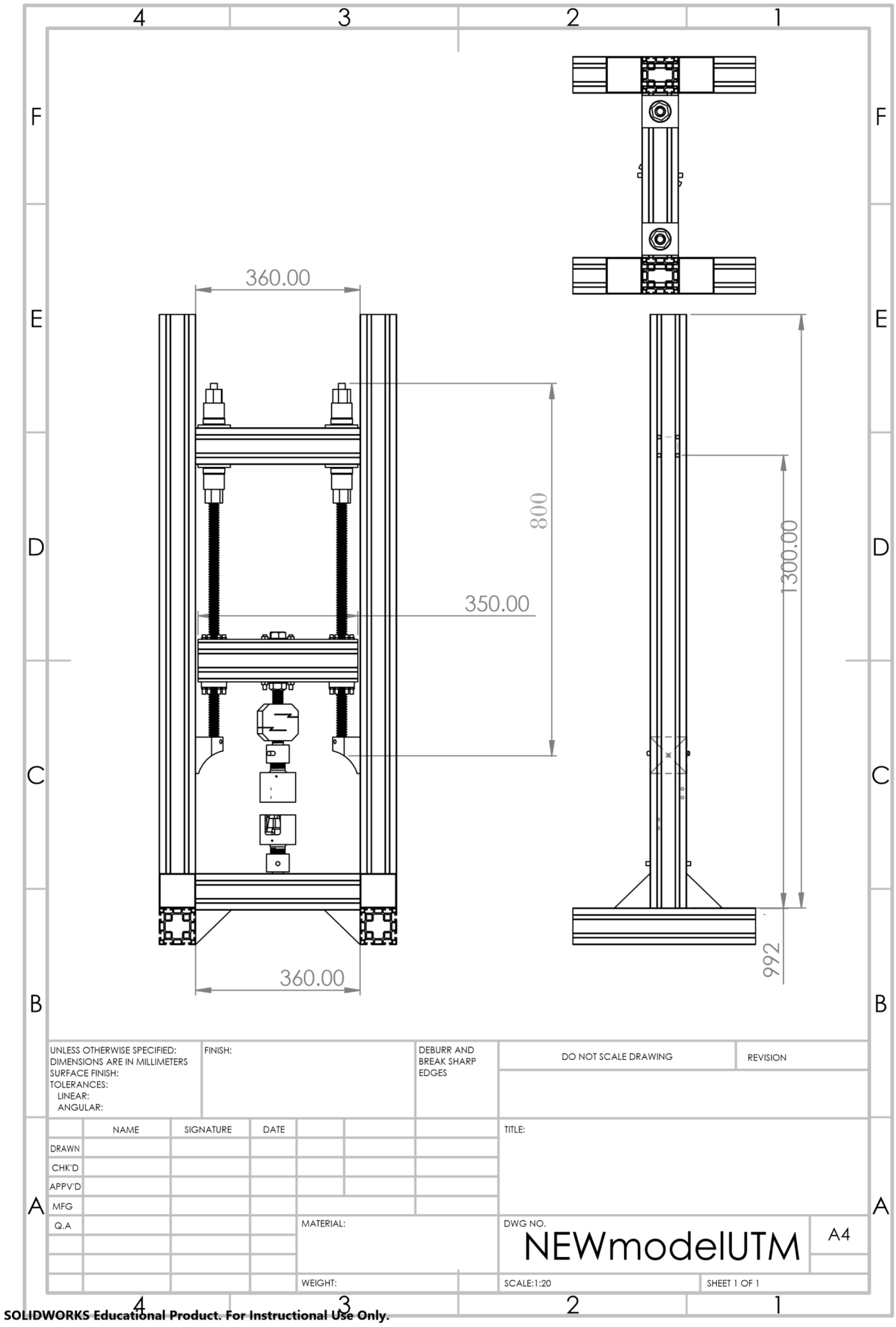

Figure 4: 2D Assembly Drawing of the proposed UTM

In order to hold all the system together a frame needs to be made. The design was started with a hand sketch which later transformed into a CAD model using the SOLIDWORKS software as seen in Figure 4. With initial model which provided the literature review for this project uses a wooden frame. As wood is heavier and bulky for the same structure, a structure with good strength to weight ratio was prioritized. As there is no requirement for a heavy material like steel, at the same time, due to availability of the material online, extruded Aluminum enclosures were selected for this project as it is easy to design and assemble, robust and flexible.

The selected Aluminium extruded profile is easy to machine and can be fitted with various fittings like angle brackets, T-slot nut, corner bracket and various screws(M12 ans M8).

The bolts used for the assembly are M12 which were used for joining two profile members rigidly and permanently while M8 bolts are for T-slot nuts and and angle brackets.

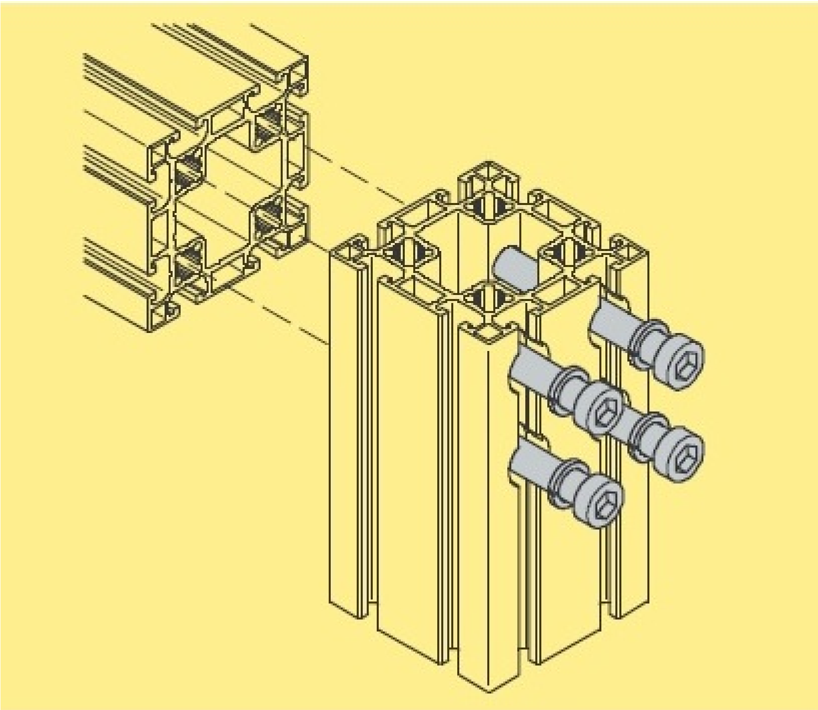

Figure 5: M 12 screw joints

The screwed joints are used for fast assembly after drilling and can withstand high load. For right angle profile joints, the screwed joints provide a high structural strength within a limited space.

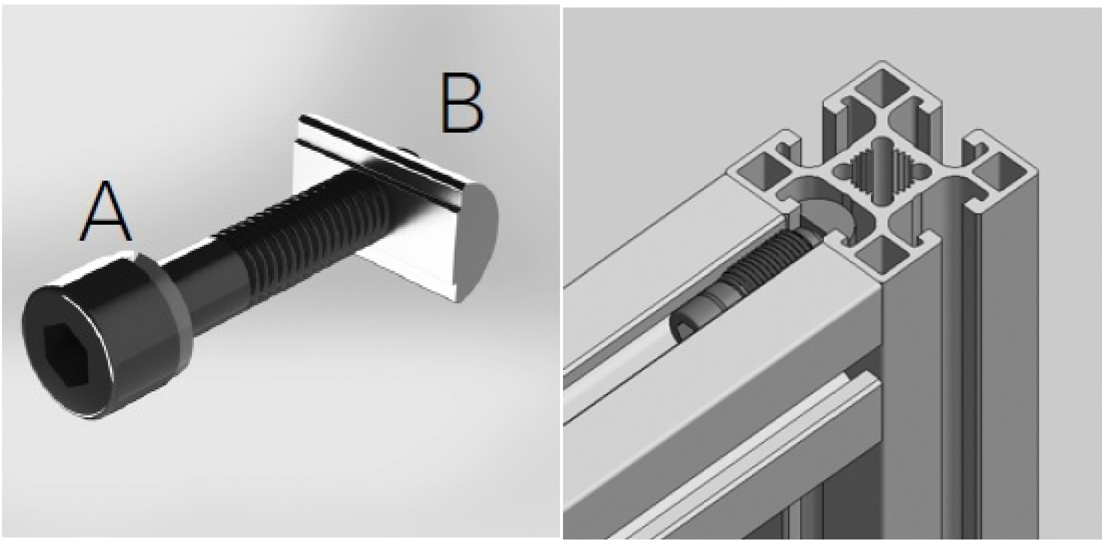

Figure 6: T-slot nuts

T-slot nuts slide easily through the profile groves making it possible to tighten various members together without machining.

The bolts, external features and data sheet are also provided in the company data sheet [17].

The frame assembly consists of mainly a pair of side members, a top and bottom member, a pair do base members. The detailed parts can be see in Figure 7.

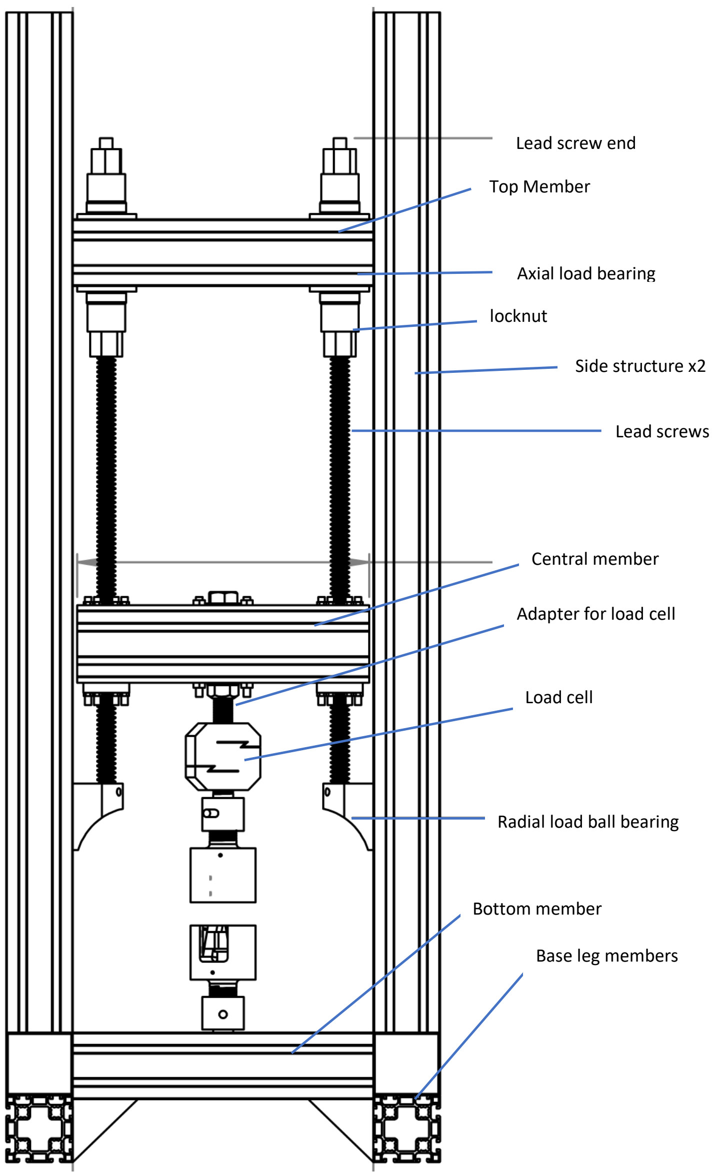

Figure 7: Labeled assembly drawing of the machine

5.1.4 Lead Screw

The main function of a lead screw is to convert rotary motion into linear motion. A pair of lead screws figure are used which provides two functions, one to move the central member up and down for a tension or compression test, and the other to provide a parallel support and ensure its accuracy in a straight movement [41].

There are various types on threads used in a lead screw, with each type has its own advantage, they are:

• Square thread: most efficient and carries high load but difficult to manufacture, hence is expensive.

• ACME thread or trapezoidal thread: easy to machine less efficient than square threads, but due to its 29 degree (30 degree for trapezium) thread angle it provides higher strength. Its motion is two directional.

• Buttress thread: It uses triangular thread which uses both properties of the square and ACME thread but can only carry load in one direction.

With all the properties mentioned above, the ACME thread was used for this project, with a Tr 22x5 (Trapezium thread, diameter x pitch) as shown in the data sheet[41]. The resulting output torque for raising the load and lowering the load were calculated, the detailed calculations can be found in the appendix 9.3 [13].

5.1.5 Round And Hexagon Nuts, and built in Flange Nuts:

Round and hexagon nuts are nuts with same diameter and pitch fitting the lead screws, locks it in place. The material specifications (ISO 2901/2903) and size are provided in the data sheet in the appendix page. These nuts are meant to restrict the lead screw from slipping vertically up and down and also ensures the load is carried by an axial load bearing as shown in the Figure 7.

Flange nut is the part that attaches the central member and ensures the up and down movement of the whole member. The nut travels only when the lead screw starts to rotate and locks in place when the motion stops. This functionality of flange nut can be seen in most modern electronically controlled servo motor powered UTM and other such devices [41].

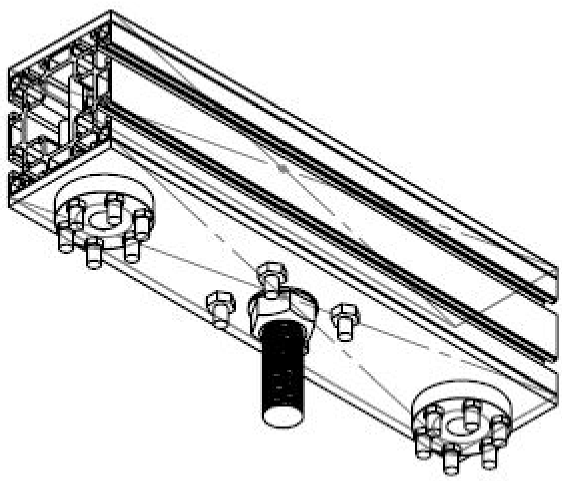

Figure 8: Flange nuts attached to central member

5.1.6 Contact bearings

Each bearing type has different characteristics, based on its design and load conditions the best type is selected. For example, deep groove ball bearings can accommodate moderate radial loads as well as axial loads.

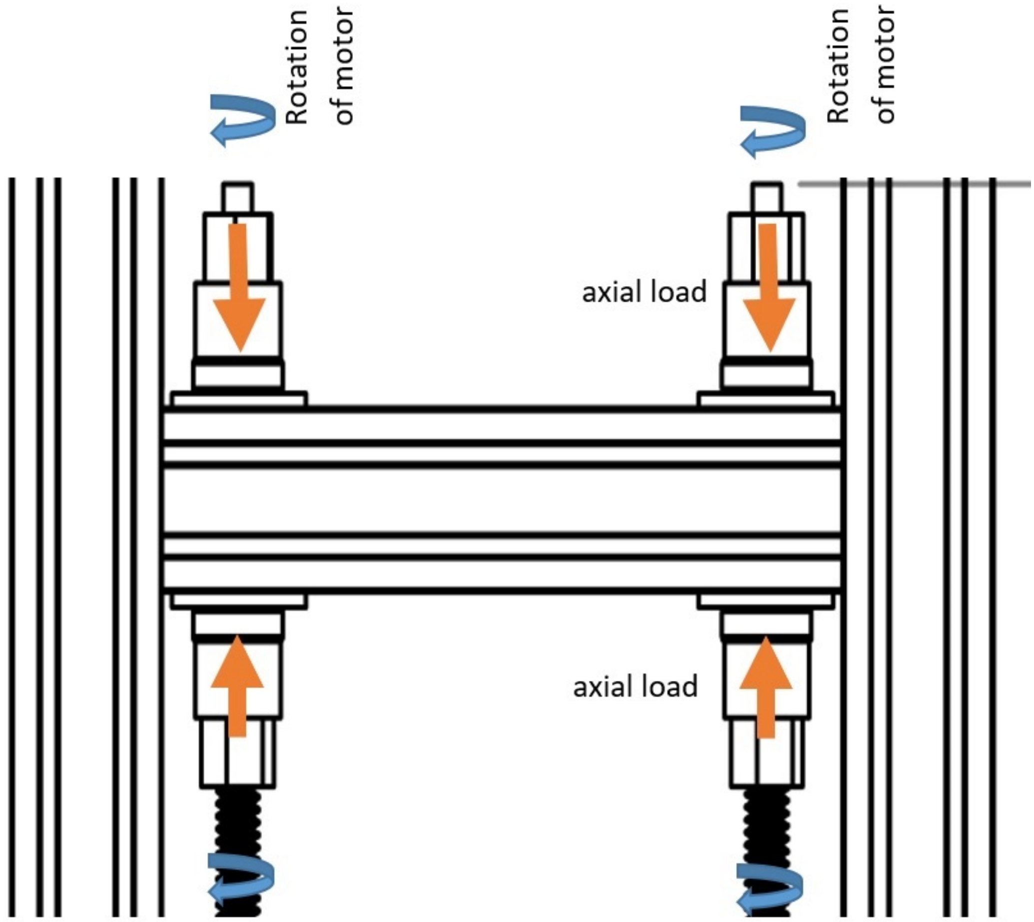

Figure 9: contact bearings load direction

Bearings mainly have two purpose, one is to minimize friction between moving parts and also to hold axial or tangential load. In general two types of loading are considered, one is axial loading and radial load or tangential load. The bearing used for the project is a single row deep groove ball bearing [7], which takes the axial loads from each lock nuts provided to hold the lead screw in place. A single row deep groove ball bearing is used to carry radial load but it can also take up considerable amount of axial load. The retainer keeps the steel balls in position and the groove below the steel balls is the inner ring and over it is the outer ring. The outer ring, called outer race, is normally placed inside a bearing housing which is fixed, while the inner race holds the rotating shaft. See Figure 8 for the details.

Another set of single groove ball bearings were used to hold the lead screw in place parallel to the structure, it mainly carries radial loads from the lead screw and provides a smooth less friction for rotation. Depending on the shaft diameter and magnitude of radial and axial load a suitable type of bearing is to be chosen from the manufacturer's catalogue, either a ball bearing or a roller bearing [23].

5.1.7 Load Cell

A load cell is a transducer which converts mechanical force into a measurable electrical energy. There are various types of working principles used in a load cell, some of which include hydraulic, pneumatic and strain gauge load cells. The one that is cheaper, highly sensitive, and less bulky and gives a moderate accurate value is the strain gauge load cell. A strain gauge load cell comprises of a solid metal body onto which strain gauges are stuck to. The body can be made of various types of sturdy yet elastic metal. Which can reform its shape within limits. Various metals like aluminium, alloy steel are used.

It uses the Wheatstone bridge principle, see Figure 10: when a load is applied, the load cell slightly deforms, the strain gauge which are basically flat metal coils also change in shape, in turn this leads to change in electrical resistance of the strain gauge, which later measures as a voltage change. This change in voltage will be proportional to amount of applied load. As the voltage output for the load cell used is very minute and the sensitivity is about 2mV, an amplifier is required for conversion. There are many types of amplifiers available, for this project a cheap and readily available one was used, which is " HX711", as the arduino library for this was available online and was compatible to the used load cell specifications [32][21].

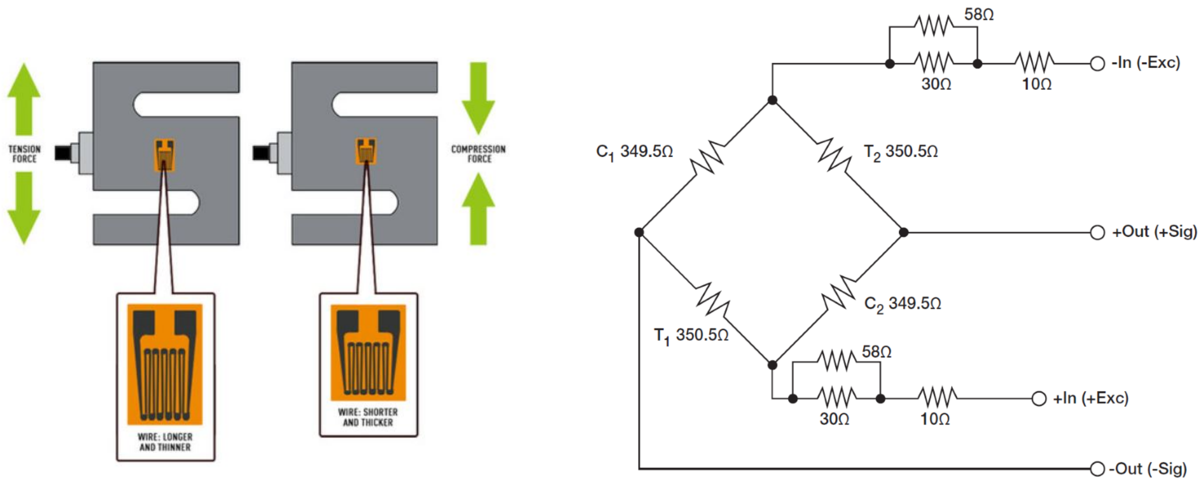

Figure 10: Load cell and Wheastone bridge

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5.1.8 Stepper Motor

A Stepper motor is a motor that moves in discrete steps, after each step the motor holds up position. Inside the motor, it consists of magnetic gear shafts. The electromagnetic fields created in the gear shaft generate a holding torque, holding the rotor in place. Stepper motor ranges in various sizes and capacity, based on torque and speed.

A stepper motor is usually used for three conditions that is, precision positioning, speed control and low speed torque, without any feedback loop, for example stepper motors are widely used in household 3D printers. A stepper motor may have any number of coils. But these are connected in groups called "phases". All the coils in a phase are energized together [14].

There are many variation based on wiring but depending on phase there are unipolar and bipolar coils. Unipolar drivers, always energize the phases in the same way. One lead, the "common" lead, will always be negative. The other lead will always be positive. Unipolar drivers can be implemented with simple transistor circuitry. The disadvantage is that there is less available torque because only half of the coils can be energized at a time. Bipolar drivers use H-bridge circuitry to actually reverse the current flow through the phases.(for bigger size motors a microstep driver is used, which is explained in the next section). By energizing the phases with alternating the polarity, all the coils can be put to work turning the motor.

The motor shaft moves to lock itself into place in front of an attracting electromagnet, each magnet represents one step. It is, however, possible to move the motor shaft into positions between steps. This is known as micro stepping. In a hybrid stepper motor, a micro stepping-enabled motor driver can position the rotor in an intermediate position between the coils as shown in the Figure 11.The advantage of micro stepping is that it can provide high precision position but this occurs at the expense of output torque.

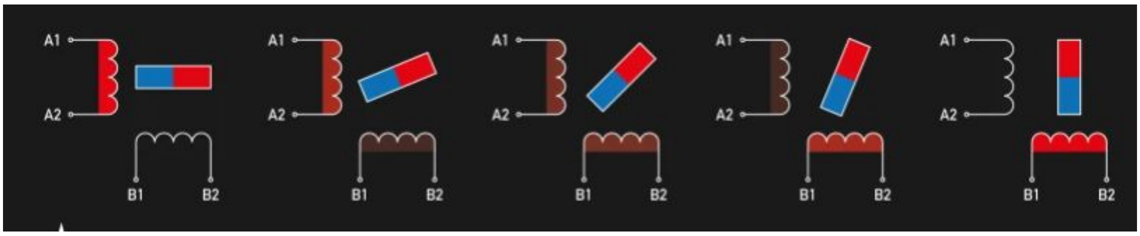


Figure 11: Different rotor positions using Micro-stepping [31]

The one used in this project is a bipolar stepper motor with resolution 1.8deg, 200 steps, and 2.8Amp stepper motor (AMP57TH76-4280). It requires a 4 wire connection, voltage reversal and external power source, for which a driver module is required. With computer controlled stepping each rotation and step can be precisely controlled. A stepper motor is the ideal choice when it comes to precision position and very slow rotation rather than opting for gears, as its often used in 3D printers, actuators etc [33][12].

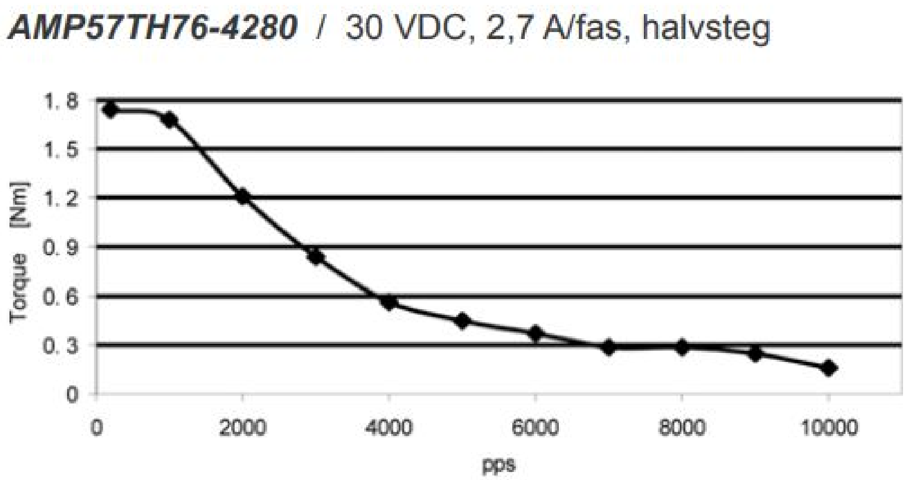


Figure 12: Stepper motor Torque vs pulse per second graph [33]

The Figure 12 shows the torque output of the used motor compared to its rotation speed, where 1RPM = 6.67 pulses per second/ half-step. The speed of the motor and its control is done through the arduino code used in this project. By changing step frequencies and time delay for each step, the angle of rotation and speed in RPM can be controlled within the codes provided in the appendix 9.5.

5.1.9 Stepper Motor Driver

To drive a big stepper motor, use of H-bridge is not ideal, hence this requires a dedicated stepper motor driver module. This electronic device enables the user to improve and use micro-stepping in a stepper motor by outputting pulse signals. Microstep drivers are available in a range of voltage and current ratings. The difference between them is the voltage and current ratings.

The SMD-4.2 driver as seen in Figure 13, receives logic signals “Step”, “Direction” and “Enable” and convert them into motor commutation. The motor’s shaft moves one angle step (or microstep) as the driver receives one “Step” signal. One step (or microstep) executes as the front edge of the voltage pulse on the “STEP” input. Rotation direction depends on the voltage level and switches by changing voltage level on the “DIR” input. The motor can be immediately stopped by the active signal on the “EN” input [39].

The SMD has a voltage input of 12 -48 VDC, gives a maximum output current per phase of 4.2 Amp and a minimum output current per phase: of 1.2 Amp. The stepper motor is inputed with a 2.8Amp current per phase with this stepper motor driver and can microstep to 1, 1/2, 1/4, 1/16 modes.

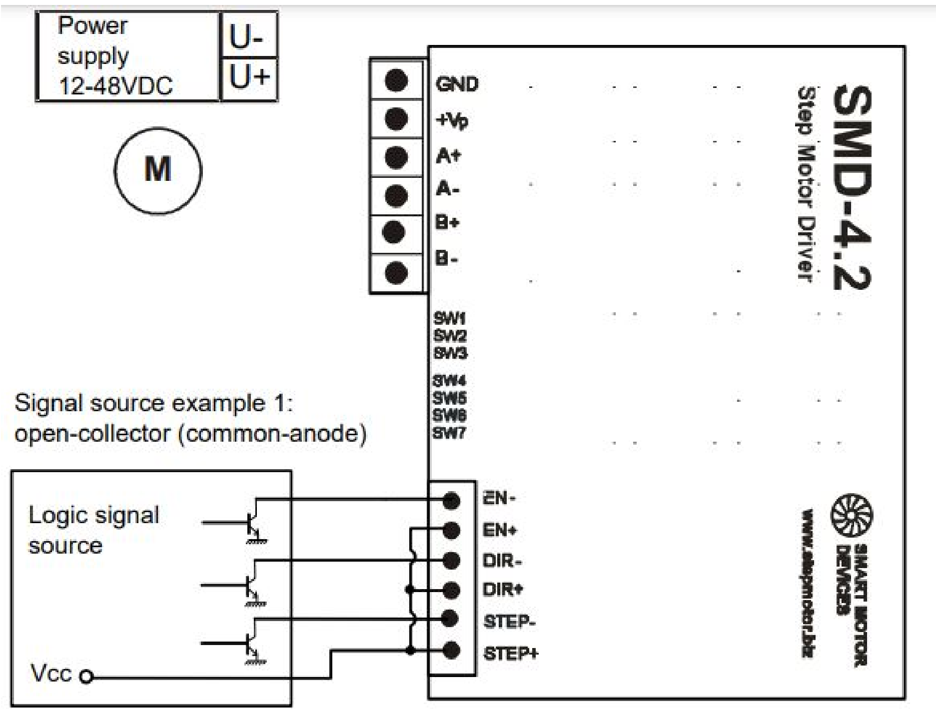


Figure 13: SMD connections and circuit [39]

5.1.10 Planetary GearBox

A planetary gear train is a type of epicyclic gear system consisting a combination of gear trains with a planet engaging both a sun gear and a ring gear, see Figure 14. Planetary gear sets can be used for a variety of purposes, mainly for power transmission purposes.

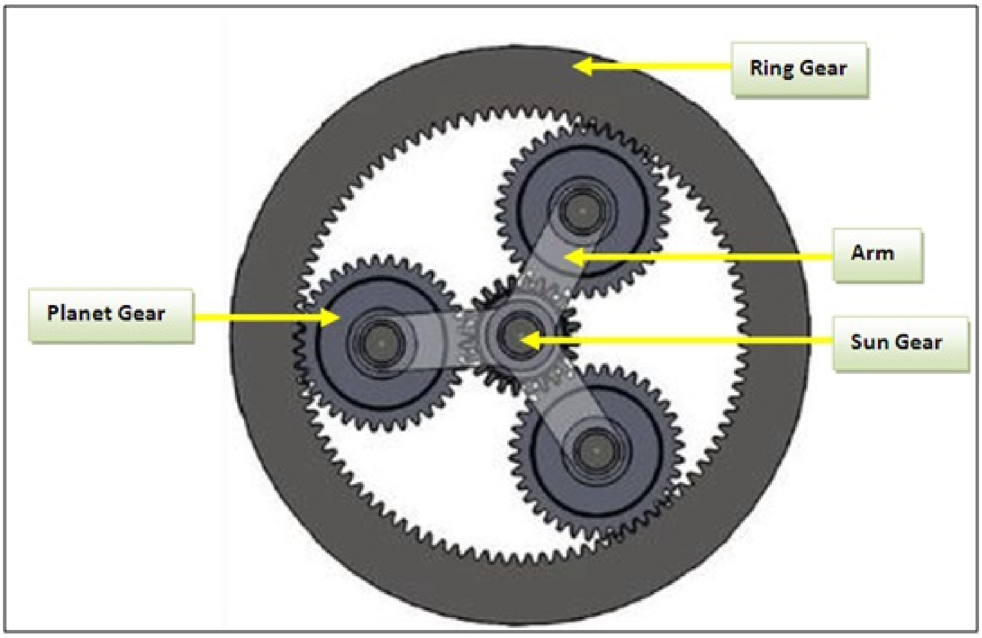


Figure 14: Planetary Gear Train

The planetary gear with a gear ratio of 20 gives an output torque of 32.3Nm for motor running at 75 RPM (maximum) and an output torque of 5.7Nm at 500RPM (0.3Nm output torque of motor).

$$T_o = T_m \cdot i \cdot \eta \tag{1}$$

where, T_o is Torque output of gear, T_m is Torque input from motor, i is gear ratio and η is efficiency.

As the planetary gear transmits torque and power from motor to the lead screw. For providing the lifting torque of 9.8Nm to the lead screw in order to lift the 5000N of load (see appendix 9.3 for lead screw calculation), the motor must provide an output torque about 0.5Nm with a rotational speed of around 400RPM (full step), which is well within the motor torque range (assuming efficiency of gear box to be around 90percentage as per company standards).

Using a gear the output torque is increased with the expense of speed and the backlash is reduced by the optimization and advancement of the gear geometry [16].

The data sheet provided in the appendix shows the nominal output torque provided by the gear box of around 42Nm. The motor shaft and gear box are coupled using the inbuilt couple provided in this equipment. The output gear shaft and lead screw was later joined using a flexible coupling, see Figure 15. The gear box provides enough torque necessary for the calculated torque required by the lead screw.[16]

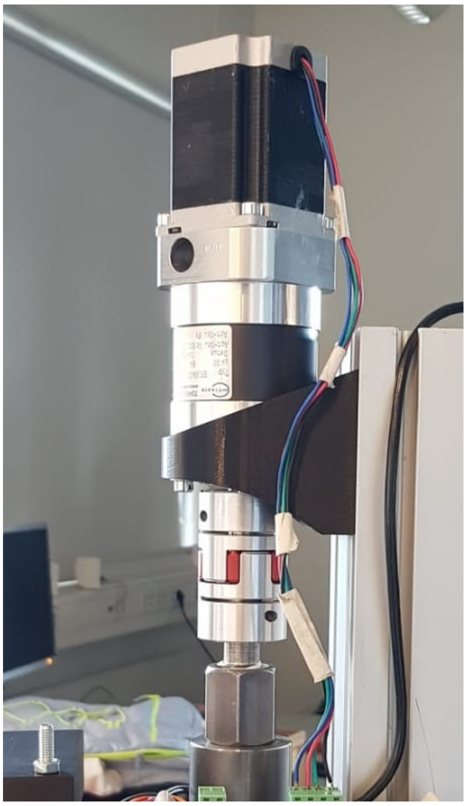


Figure 15: Stepper motor, Gearbox and shaft coupling

5.2 Electronics

5.2.1 ARDUINO Board

Arduino is an open-source electronics platform which allows users to program micro-controllers easily [3]. Over the years these arduino boards have been used by students, researchers and hobbyists from around the world and branches to build variety of projects. Their donations and experience to the open source has added up to the amount of knowledge available required for this project. See Figure 16 for all the parts of an arduino board.

An Arduino board consists of a microcontroller and can be programmed using simple C++ programing. It only requires a mini-B USB cable to connect this board to the PC. Also, an Integrated Development Environment (IDE) which is a part of the software, is used to program this electronic board, and allows the user to write and upload the firmware code into the board through the PC. Due to its cheap cost, easy programming environment, flexibility as well as easy access of knowledge, Arduino Board was chosen for this project. But among various versions of this board only Arduino Nano was found best fit due to its miniature size required number of pins.

The Arduino Nano uses a ATmega328P microcontroller. It has the same microcontroller as an UNO in a smaller package. It has 14 digital input/output pins, 6 pins with pulse width modulation and 8 analog outputs.. It can be powered through USB along with a 5V pin. It is a great alternative to its larger counterparts. In-order to work with the processor pins need to be soldered and fixed into the bread board while prototyping the project. See Figure 16.

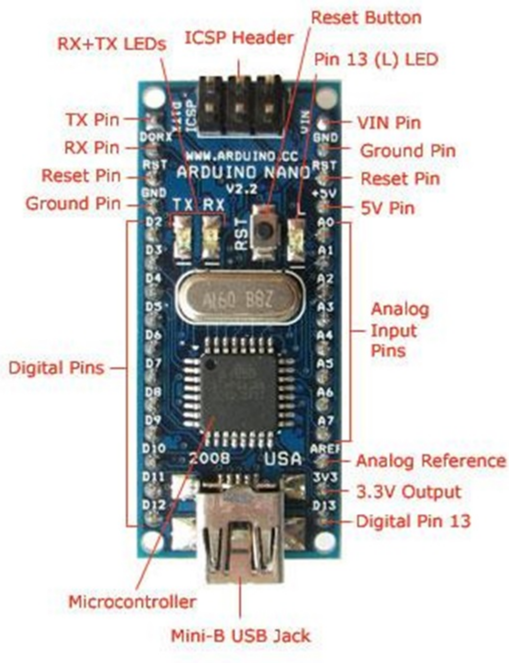


Figure 16: Arduino Nano Board using ATMEL ATmega328P 8 bit microcontroller

5.3 Circuitry

A schematical representation of the circuit was made, representing the various components and connections as shown in Figure 15.(The detailed layout can be found in appendix 9.6)

The electric circuit was designed as shown in Figure 17 and connections were tested using a bread board during trial. As shown in the circuit diagram. Digital pins D2 and D4 of arduino nano is connected to negative pins of stepper motor driver. Pin D2 connects to the Step pin and D3 connects to the Direction pin of the respective motor drivers. The properties of these pins are coded in the adruino IDE as required. For the motors external power was given my means of a 250W Switch Mode Power Supply, the outputs of which were connected into the respective pins provided in the Stepper motor drivers.

For the load cell connections the output wires were connected to the amplifiers as explained in further section, and the two output connection such as the D out and serial clock input are connected to analog pins A0 and A1 respectively. Furthermore, the input voltage and ground wires are connected to their respective connections as well [2].

Switches for manual control such as up, down and speed are also provided at pins D12, D11 and D10. The circuit was connected as per mentioned above, first in a bread board and was test run before soldering into a matrix board for the final product.

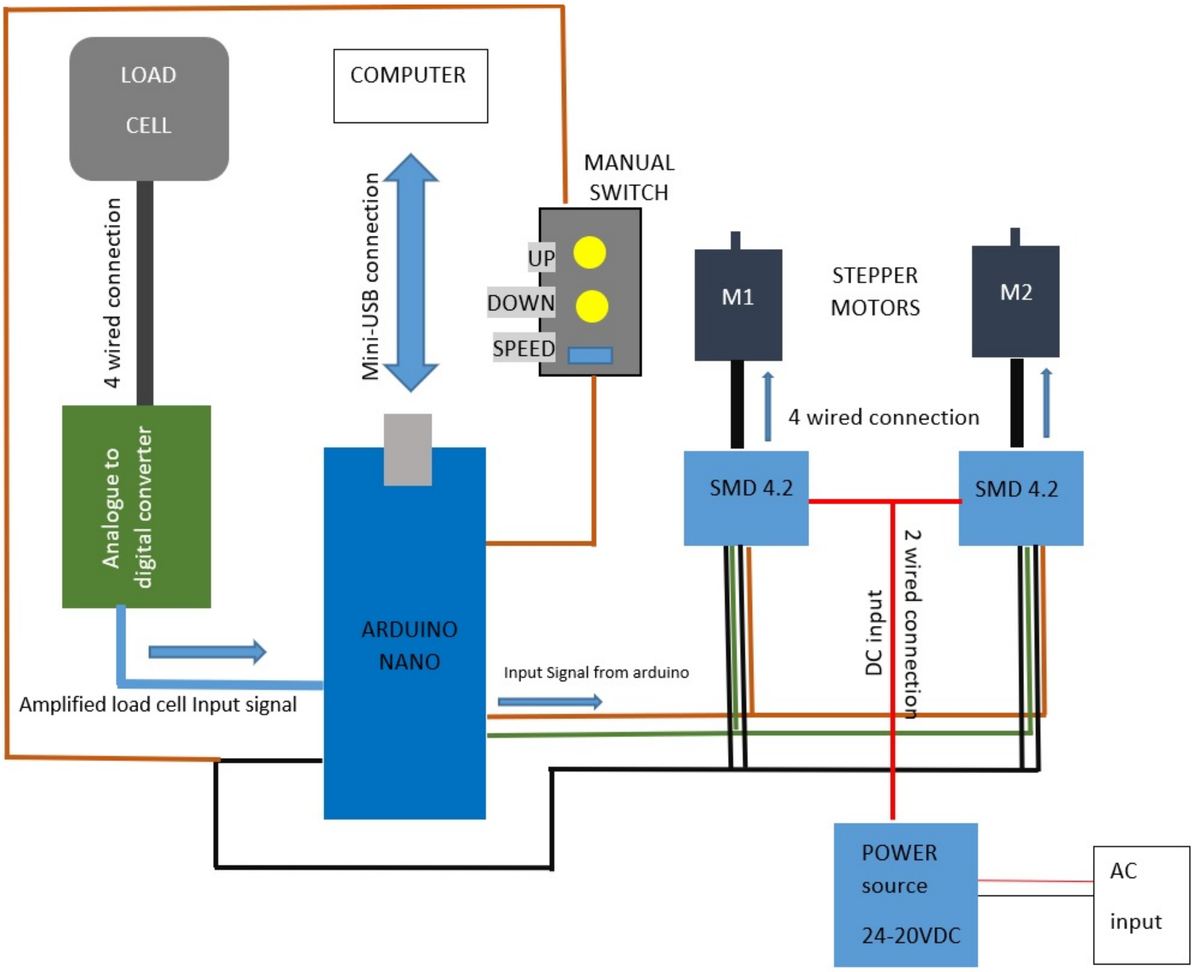


Figure 17: Circuit Diagram

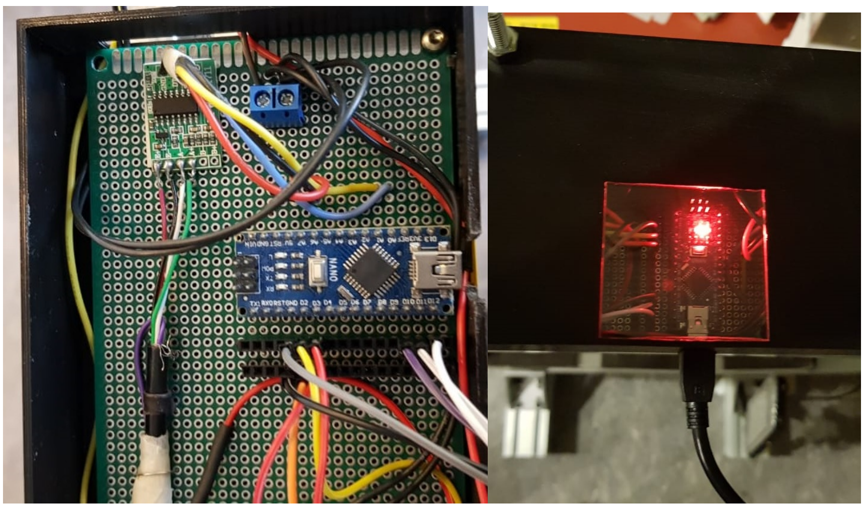


Figure 18: Circuit connections

5.3.1 Steps on calibration of load cell:

The load cell acquired from the company does not provide any fixed zero error value or any electronics with it, hence calibrating this load cell before use is a major step that needs to be taken into account.

For calibrating the load cell an arduino code is required, which could run the load cell and see the changes happening with application of various loads, for this a precise known weight was used to calibrate the value. The algorithm used is explained below. The steps involved for acquiring the calibration factor setting up the zero error is shown in Figure 19 [21][32].

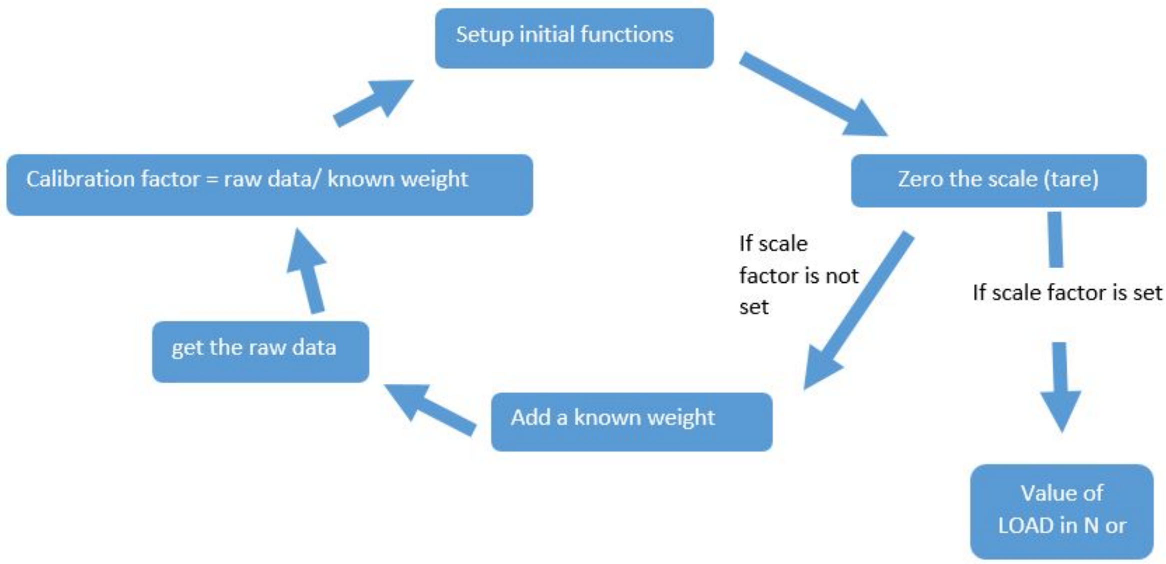


Figure 19: calibration of load cell

Algorithm 1 Load cell basic code after setting up calibration factor

```
#include <HX711.h>
#define DOUT A0
#define CLK A1
HX711 loadCell;
float scalefactor = -882.86;
void setup(){
  Serial.begin(9600);
loadCell.begin(DOUT, CLK);
loadCell.set_scale();
loadCell.tare();
loadCell.set_scale(scalefactor);
  Serial.print("load in kilograms : ");
}
void loop(){
float rawvalue = loadCell.get_units();
       float W = (rawvalue/5)*10;
loadCell.set_scale(scalefactor);
  Serial.println(W);
}
```

The load cell used for this project is a 10KN load cell. The details and specifications of this load cell were obtained from its product data sheet and was then calibrated using the same code. The detailed specifications is provided in the appendix.

5.4 MATLAB Coding

The MATLAB analysis is started by initialising the image processing function. In order to receive the value from arduino into the MATLAB as well as give inputs into the arduino monitor from MATLAB, a serial communication is required between MATLAB and arduino functions regarding serialport finding, reading and writing of data were searched from the MATLAB forums and applied here.

5.4.1 Image Processing

Real-Time Object Detection and Tracking technology is used to track the test piece and the blobs marked on them [43][38].

Image Processing Toolbox provides a comprehensive set of reference-standard algorithms and workflow apps for image processing, analysis, visualization, and algorithm development. It is possible to perform image segmentation, image enhancement, noise reduction, geometric transformations, image registration, and 3D image processing.

Image Processing Toolbox apps can automate common image processing workflows. This allows to interactively segment image data, compare image registration techniques, and batch-process large data sets. Visualization functions and apps let us explore images, 3D volumes, and videos; adjust contrast; create histograms; and manipulate regions of interest (ROIs).

The algorithms can me accelerated by running them on multicore processors and GPUs.

Image processing is a complex process that required extensive research and through study to understand the principle of working and the various functions. The detailed image processing of the required functions was found in Image Acquisition Toolbox MATLAB user guide [27].

For image processing in MATLAB, video processing is initialised where the number of frames per Second is set. Here to get a particular frame 'getsnapshot()' function is used and the acquired image is buffered.

There are two types of input for real-time image processing, live feed and video file, and the image acquisition toolbox for camera lists the detailed list after getting all the addons. And the base working is like Preview > Start acquisition > stop acquisition and export of data. From this process the required source code is obtained. See Figure 20 for the various steps involved in image processing.

MATLAB Computer vision:

Use of images of video , algorithm to detect classify and track images. Many applications from satellites of NASA to robots, face detection, Pattern detection of parts in industries etc.

Object detection and tracking methods:

- Segmentation blob analysis
- Template matching Features critical to computer vision:
- Edges and corners
- Template
- SURF

- MSER Hungarian algorithm Motion based object tracing: KLT tracking

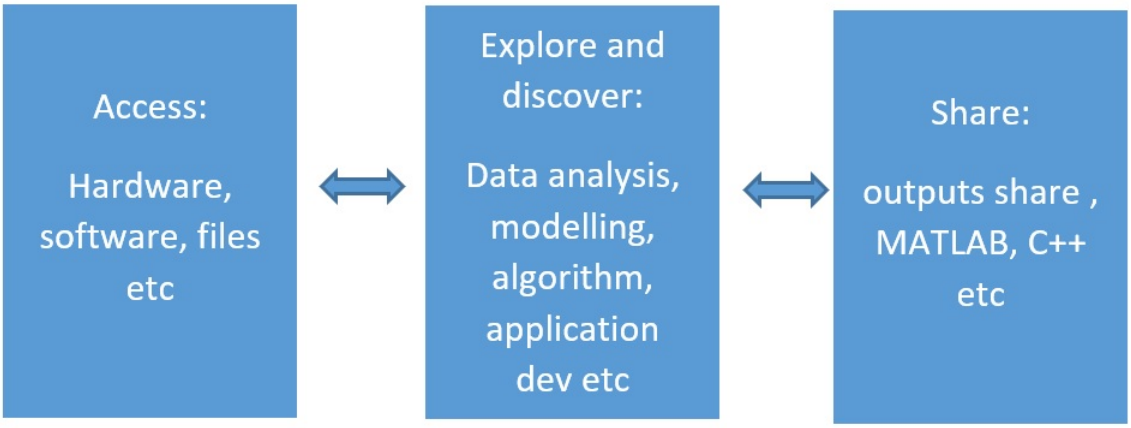


Figure 20: Image processing

To make external camera compatible with MATLAB, BASLER provided certain functions available online for downloading [25].

baslerFindCamera: returns a cell array containing the camera index and the camera name.

- BaslerCameraInfo: returns a struct containing all parameters of the selected camera.
- BaslerSetParameter: sets a camera parameter.
- BaslerGetParameter: returns the selected camera parameter.
- BaslerSetROI: sets the region of interest (ROI).
- BaslerPreview: displays a preview image.
- BaslerGetData: captures and returns the selected number of frames.
- BaslerSaveData: captures and saves the selected number of frames to disk.

One of the issues encountered here was that in some cases MATLAB fails to detect or recognise the image acquisition hardware (camera), is such a scenario it is required to open the image acquisition toolbox and refresh the hard ware settings.Figure 21

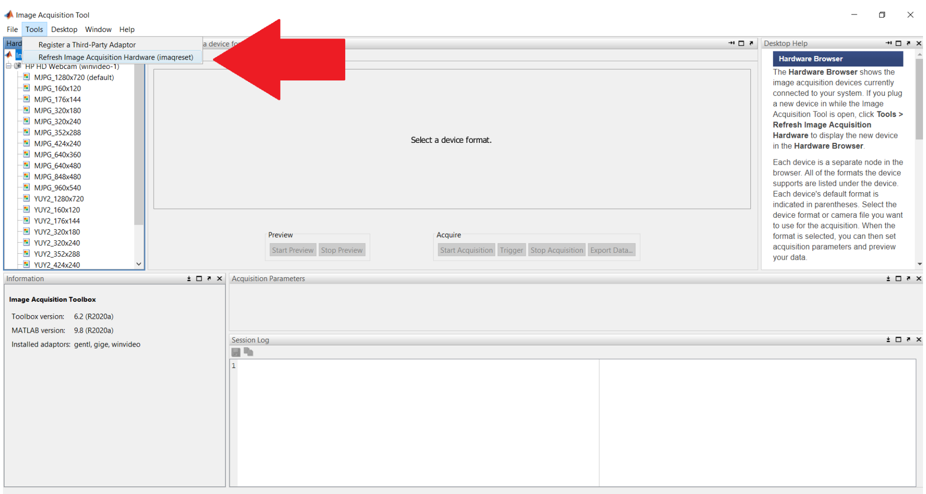


Figure 21: Setting up of Image acquisition equipment

5.4.2 APPS Needed To Be Installed In MATLAB For This Project

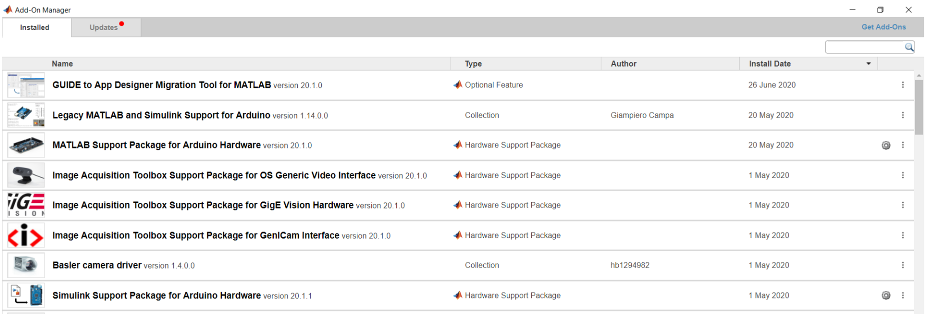


Figure 22: MATLAB app package

- Basler camera driver
- Image acquisition toolbox Support package for GigE vision hardware
- Image Acquisition Toolbox Support package for GenICam Interace
- Guide to PP Designer Migration Tool for MATLAB

5.4.3 Image Tracking

There are various ways to track points like point tracker, motion based tracker algorithm, MSER Hungarian algorithm and motion based object tracing like KLT tracking and multiple object tracker. For example, blob analysis is a combination of point tracker and motion tracker algorithm, which is used to track the centroid, see Figure 23. Properties like brightness, contrast, exposure, frame rate and frames per trigger are set manually [30][27][28][29].

Functions

Detectors

ocr	Recognize text using optical character recognition
readBarcode	Detect and decode 1-D or 2-D barcode in image
acfObjectDetector	Detect objects using aggregate channel features
peopleDetectorACF	Detect people using aggregate channel features
vision.CascadeObjectDetector	Detect objects using the Viola-Jones algorithm
vision.ForegroundDetector	Foreground detection using Gaussian mixture models
vision.PeopleDetector	Detect upright people using HOG features
vision.BlobAnalysis	Properties of connected regions

Figure 23: Types of detectors

Algorithm 2 Command to get frames

frame = getsnapshot(vid);
diffimG = imsubtract(frame(:,:,1), rgb2gray(frame));

Steps Involved In Image Capturing:

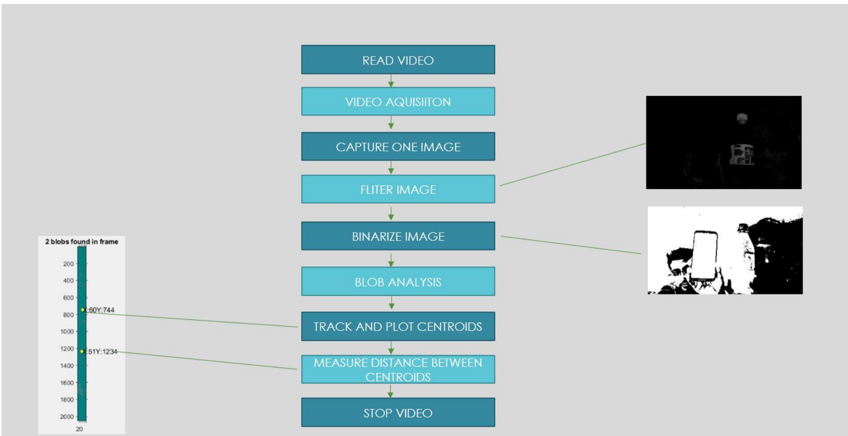


Figure 24: algorithm flowchart for image acquisition and processing

Filter: To get one frame from the video feed, the red channel is selected as the blob color is red, see Figure 21 and this is subtracted from the grey image. The image thus acquired is binarized so that the only pixels that appear would be of red colour. Change in threshold values depending on grey scales can also be done to improve the identification of points [8].

Tracking of point : The detector used for this project is “vision.BlobAnalysis”. This function computes statistics for connected regions in a binary image, track a set of points and call object with arguments, as if it were a function. This property is tuneable as the user can change properties anytime. The input arguments for this would include function such as "bw" (binary image) which can be obtained through image aquisiton and threshold values. The output arguments include functions like Area (number of pixels in labeled region), centroid (centroid coordinates) and bounding box [1] [29][38].

Measuring strain : 'Drawnow' function is used to refresh the loop for every frame acquired, in which the centroid position of each tracked blob are considered for strain measurement. Since there are only two blobs present, an algorithm is used to recognise these points and the measure the distance between these two points. The difference between the change in length to the original length is used to find strain. The code used for blob tracking can be found [40].

5.5 Camera

A digital camera is used for the real time image tracking for measuring the change in length. The model used for the machine is acA2440-35um - Basler ace.[19][25]

Specifications of Camera :

- Sensor - Sony IMX 264 COMOS Sensor
- Resolution - 2448 x 2048 pixels.
- Pixel size - 3.45 x 3.45 micro-meter.
- Resolution - 5 mega pixel
- Frame rate - 35 frames per second
- The camera uses a USB 3.0 for powering, digital input and output
- Mono/Colour - Mono

The detailed DATA sheet for camera is provided in the appendix.

5.5.1 Camera Lens

Lens : AZURE-2514M 5MP 2/3"
Focal length : 25mm

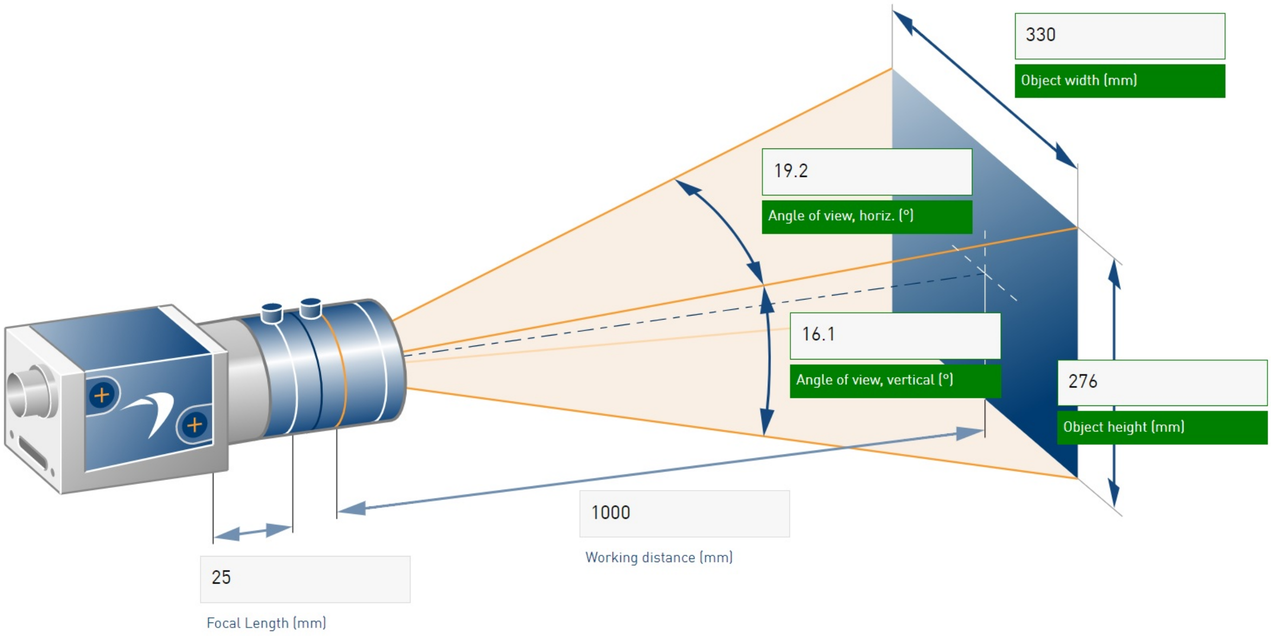


Figure 25: Camera positioning and factors

The lens together with the image sensor size of the camera define the working distance and the distance between the object that fits inside the image and the camera, see Figure 25[6]. The focal length of the camera can be adjusted to make the image sharper. The industrial digital camera have a narrow angle of view and small sensor size, compared to other commercial digital cameras, which enables it to focus sharply on a center spot with high detail. This requires external features like the right lighting conditions and minimised distortions.

Using the image acquisition tool box in MATLAB the image is captured with a resolution of 2448 x 2048. The basic principle of the program used will be to detect the points within a set of minimal pixel area in a single color background within the field of view.

By using a jig with two points of known measurement (for example 50mm), equivalent minimum number of pixels between these points will be measured in the program, and will be converted in terms of a true scale. This is based on the condition that, the working distance and focal length must be fixed, see Figure 25. The precision in measurement of length depends on the pixel resolution of the camera. For the purpose of strain measurement, change in gauge length with an accuracy of 1% of the original length will be considered [22](where, gauge length is the part of a test specimen actually being measured for elongation during a tensile test).

6 Results

From the open source site Github, sample datas were collected based on the previous attempts made by a few other engineers, for the design basis. Several iterations were made, to come up with a feasible and easy to handle model. The calculations were simulated and final machine was made using aluminium profiles to make it modular to the maximum capacity (the background data has been collected mostly based on Grey Literature provided on web sites).

6.1 Final Prototype Design

The design was extensively modified to meet the requirements of JTH. The refered design was more rugged and crude and the material used was wood. For the prototype, major changes were made in the material selection, to make it more modular and flexible. To achieve the necessary properties, the material was changed to aluminium instead of wood to withstand the load. A new type of gripper design was introduced, which is self aligning and wouldn't require any form of calibration for prolonged use. The frame of the UTM is made using extruded aluminium profile to withstand a max load of 10kN. The design flaws were rectified and simulations were run using SOLIDWORKS. Figure 26 shows the initial proposed design made using SOLIDWORKS.

Figure 26: Initial Design with rectangular gripper

For the initial proposed design alloy steel plates were used for load distribution on the member.

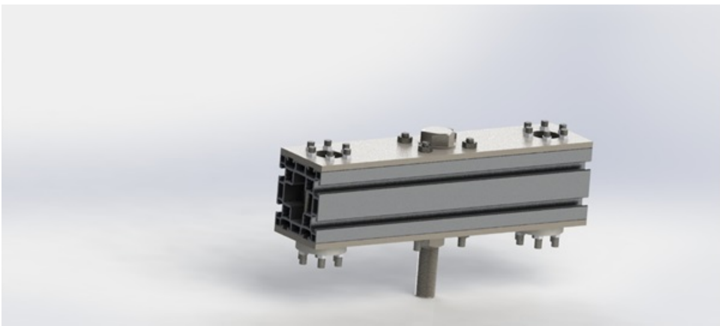


Figure 27: Modified member

6.2 Gripper Design

The gripper was initially designed to be rectangular for easy machining and self aligning and centering, making manual calibration after each testing redundant. The gripper consists of a main body with two movable wedge blocks for gripping of samples. The proposed material for making the gripper was alloy steel. Extensive simulations were run to make sure that the proposed design had the strength and other required properties to withstand the load applied Figure 28 [11].

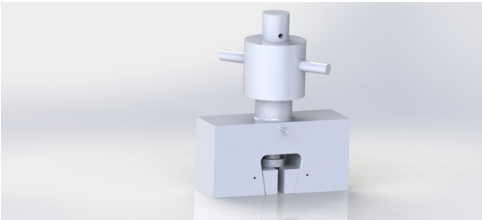


Figure 28: Initial Gripper design

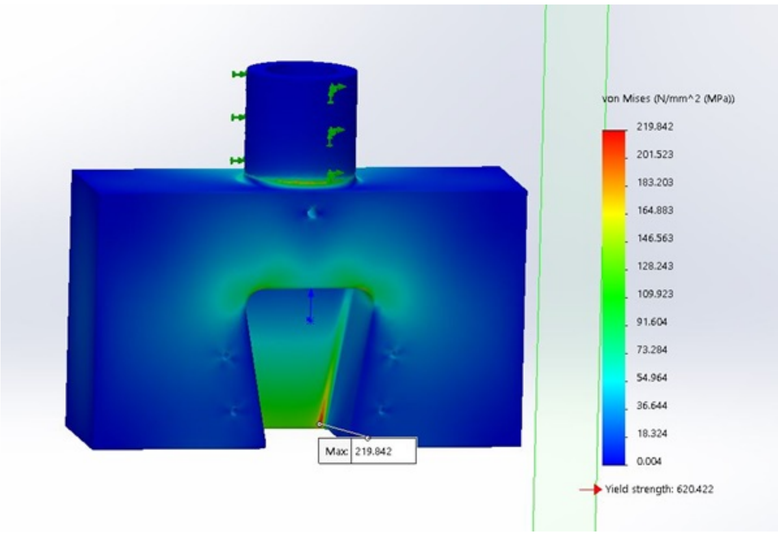


Figure 29: Simulation of Gripper

After getting the desired results the design was optimised to get a more cost effective design and the results obtained was extremely promising Figure 30.

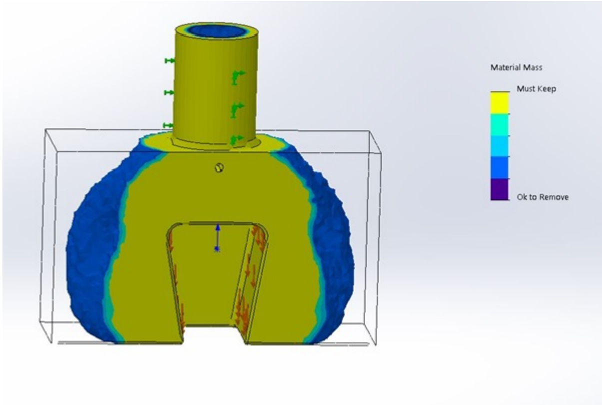


Figure 30: Optimised design

From the optimised figure a new design was made, which would drastically reduce the machining time. The new design is cylindrical and still uses wedge blocks to hold the specimen for testing and still doesn't require any calibration for aligning. Simulations were run on the new design to make sure that it can take the load, see Figure 31.

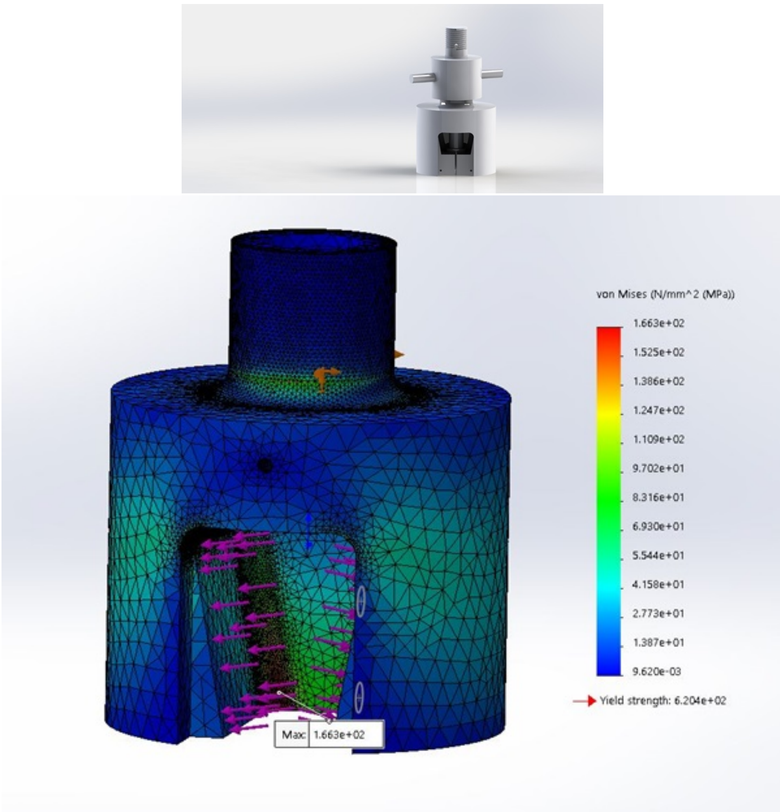


Figure 31: New gripper design and its simulation

But due to technical limitations, the created design was discarded and pre-machined set of clamps were used[42], as shown in Figure 32.

Figure 32: New Clamps used

6.3 Frame / Assembly

For strength and support of the machine, extruded aluminium enclosures were selected due to its high strength and ease of assembly. Aluminium as a material has a strength to weight ratio superior to steel. Due to its high strength, low density (compared to steel or any other structural material for the cost), alumimium TC40 profiles were used, which consists of open profiles ranging from types Light , Basic , Heavy and Ultra. For this project Basic open profiles were selected. (The detailed properties of the selected aluminium profile can be found in [17].

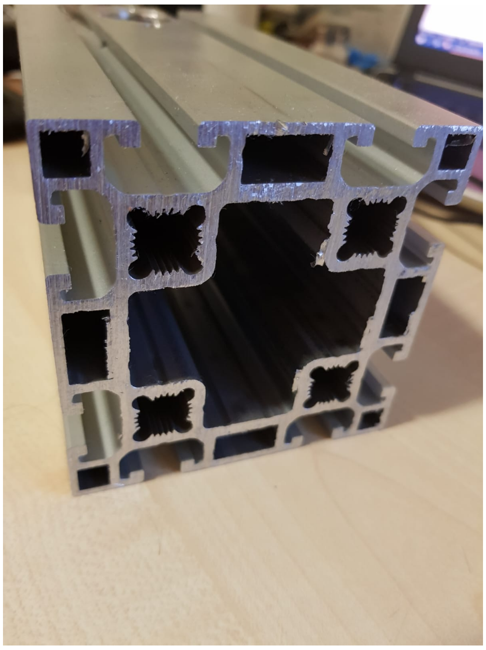


Figure 33: Aluminium profile

Strength analysis done using Solid-Works Simulation is as follows, see Figure 34:

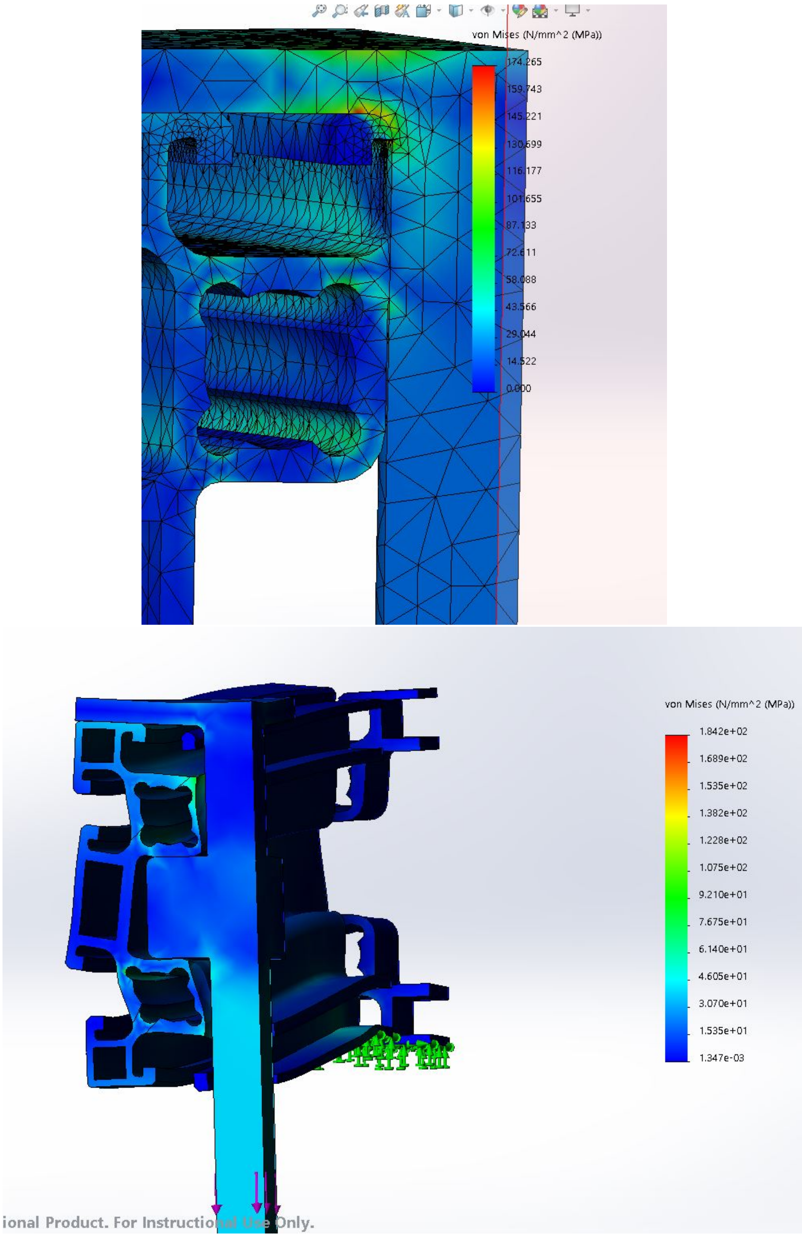


Figure 34: Simulation Analysis of the central member under load

Members of 350mm 360mm, 1300 mm and 400 mm were cut using saw belt. The measurement marking were done by hand using vernier scales to meet the precision and tolerance. To connect the members together holes were drilled with various drill-bits to meet the required purpose. Similarly holes were drilled to support the lead screws and support threads. Initially the center member was supposed to have two full length steel plates to provide additional strength, support and load distribution but due to technical limitations the plan was modified and ended with six small steel plates instead of two. The steel plates were cut with equal holes and bolted on, to distribute the load over the softer aluminum profile. There were a few modifications made on the final assembly design due to technical manufacturing limitations and other constraints without affecting the requirements.

Figure 35: Frame assembly

The end section of the lead screws were inserted into a pair of ball bearings that are being housed inside a 3D printed socket. The purpose of these bearings is to guide the lead screws in line and not lean or bend inwards. With all parts and members in place and well aligned, all the parts were bolted in permanently Figure35.

The stepper motors are fixed using 3D printed brackets using PLA material and the bracket design can be found in [40]. The brackets are designed and analysed, so that it can carry the hub and withstand the torque produced by the motor.

After completing the frame assembly the electric part of the UTM was assemble and attached on to it. The testing video of the assembly can be found in the link provided below[3].

[3]https://youtu.be/nl2pREahT_M

6.4 Setting Up Of Electrical Connections

6.4.1 Electric Connections

FIRST TEST RUN :

The code used for testing can be found in the link below. The values of load cell outputs will be displayed within this serial monitor at a given baud rate.
[4]

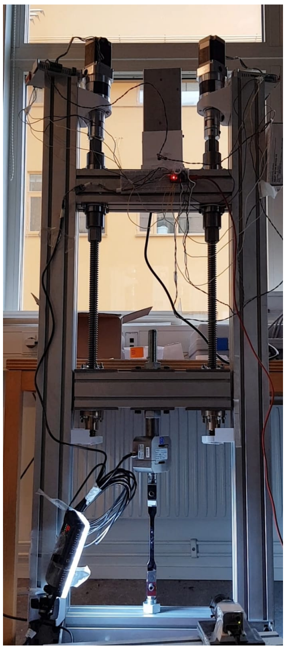
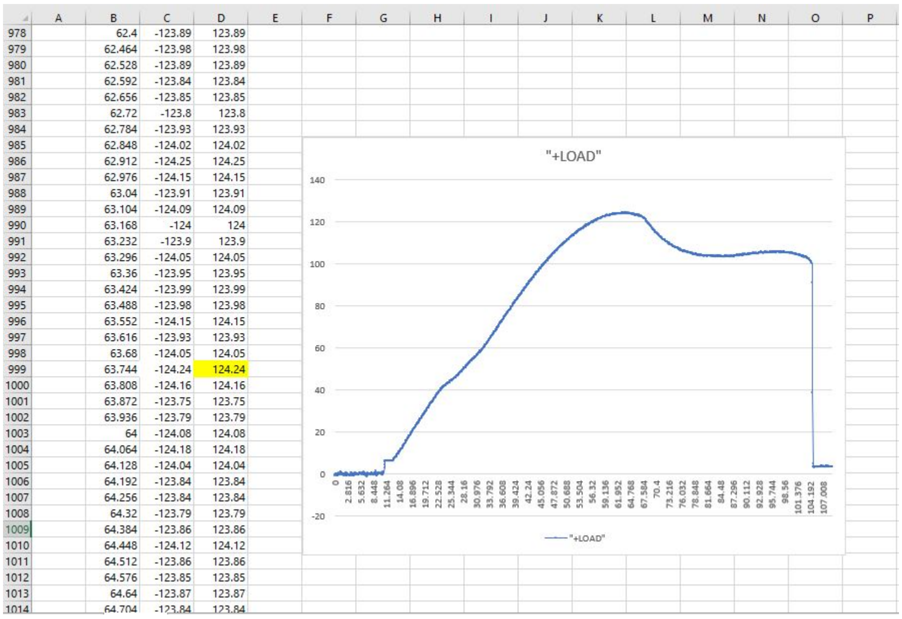


Figure 36: Setup during first test run



	A	B	C	D
978		62.4	-123.89	123.89
979		62.464	-123.98	123.98
980		62.528	-123.89	123.89
981		62.592	-123.84	123.84
982		62.656	-123.85	123.85
983		62.72	-123.8	123.8
984		62.784	-123.93	123.93
985		62.848	-124.02	124.02
986		62.912	-124.25	124.25
987		62.976	-124.15	124.15
988		63.04	-123.91	123.91
989		63.104	-124.09	124.09
990		63.168	-124	124
991		63.232	-123.9	123.9
992		63.296	-124.05	124.05
993		63.36	-123.95	123.95
994		63.424	-123.99	123.99
995		63.488	-123.98	123.98
996		63.552	-124.15	124.15
997		63.616	-123.93	123.93
998		63.68	-124.05	124.05
999		63.744	-124.24	124.24
1000		63.808	-124.16	124.16
1001		63.872	-123.75	123.75
1002		63.936	-123.79	123.79
1003		64	-124.08	124.08
1004		64.064	-124.18	124.18
1005		64.128	-124.04	124.04
1006		64.192	-123.84	123.84
1007		64.256	-123.84	123.84
1008		64.32	-123.79	123.79
1009		64.384	-123.86	123.86
1010		64.448	-124.12	124.12
1011		64.512	-123.86	123.86
1012		64.576	-123.85	123.85
1013		64.64	-123.87	123.87
1014		64.704	-123.84	123.84

Figure 37: Test phase graph

[4]https://github.com/Stephenlonewolf1010/UTM-/blob/master/UTMarduino/testing_phase/testing_phase.ino

6.4.2 Arduino MATLAB communication

Here the commands are needed to be input from Arduino to MATLAB through serial communication. And the output from Arduino is displayed in MATLAB. For this process first the available serial port needs to be found which can be done by using the command serialportlist(available). The algorithm used for this is shown below Algorithm 3.

Algorithm 3 Inputing serial port command

```
serialportlist('available') ;
s= serial('COM4');
fopen(s);
fprintf(s,'%s','M');
out= fscaf(s);
```

6.4.3 Plotting Graph

Before the image acquisition is started the plot should be initialised Algorithm 4.
X axis - Strain from Image acquisition
Y axis - Stress is obtained from Load Cell
an exit function is used to close the plot loop.

Algorithm 4 Plot initialization

```
h.plot = plot(NaN,NaN,'-k');
hold on;
h.meanPlot = plot(NaN,NaN,'-b');
data.X = [];
data.Y = [];
data.Xm = [];
data.Ym = [];
xlabel('strain')
ylabel('stress')
```

Source GUI, code and all necessary design files can be found here [40].

6.5 Control System For UTM

6.5.1 Graphical User Interface

The MATLAB App Designer is a replacement to the MATLAB GUIDE, as the future versions would be incompatible with GUIDE generated GUI's. The initial layout was made using MATLAB GUIDE which had only base function and layout, it provided the required codes needed but was not sufficient for what was required to control the equipment. The GUIDE system was not supported by latest version of MATLAB, due to all these factors and reasons, it was necessary to switch from GUIDE to App Designer. The App Designer package builds apps with a variety of components like User Interface controls(UI controls), check boxes, drop-down lists, text boxes, toggle buttons etc. It also enables the user to provide control switches that looks similar to an instrument panel. There are a lot of options available in the component gallery allowing the user to plot 2D or 3D graphs, layout tables, text area, sliders , knobs etc. See Figure 38 for the general layout of the GUI.

This package also has a feature to automatically check for coding problems using the design code analyser. One can view warning errors and debug using these integrated features and modify accordingly. There are still some unknown errors found in the code used for the project, and also some errors within the App designer were found as we require more experience with the software. The biggest catch with App designer codes is that it cannot be copy pasted or replicated on to any other platform without using the relevant packages.

The GUI needed for the running of machine was made using MATLAB App Designer. App Designer is a secondary software available where the basic interface and pages were laid out [35][26].

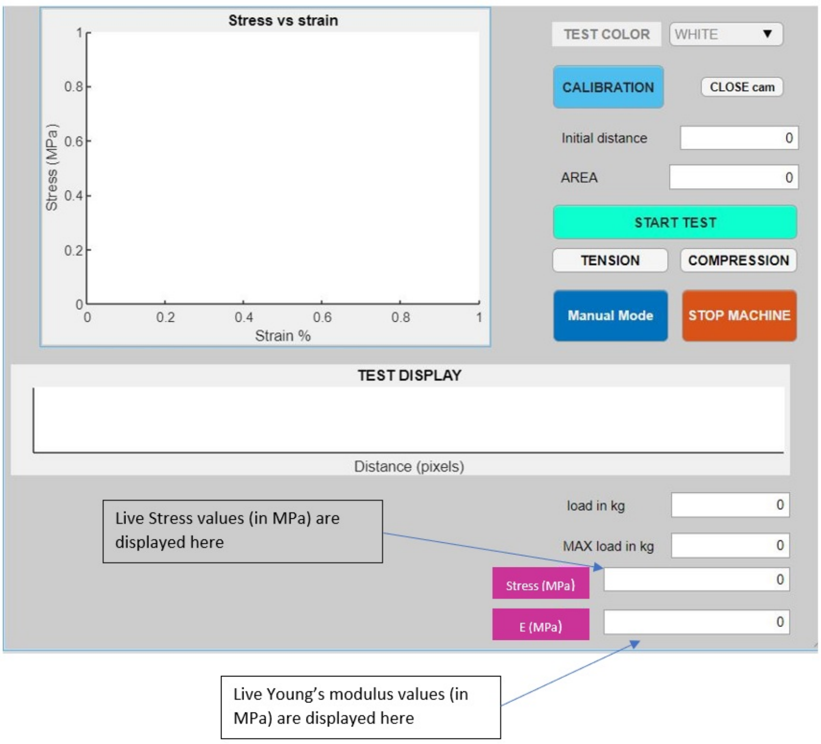


Figure 38: Graphic User Interface

6.5.2 GUI Properties

The GUI was created keeping in mind as to make it as simple as possible for a user to use it without any hassle or a detailed working manual, all the while making it look elegant. The codes for the working was previously made to check the working and compatibility and once it was seen that the codes work properly the interface was made. The interface consists of a plain grey background on to which text boxes and User Interface controls (UI controls) were placed. The detailed properties of each UI control buttons are explained in the following sub sections.

6.5.3 User Interface controls (UI controls) and Properties

6.5.3.1 Test colour

The drop down menu can be used to select the colour of test piece. Only two colour option are given as of now as the camera is black and white and the most contrasting colours are these two. See Figure 39.

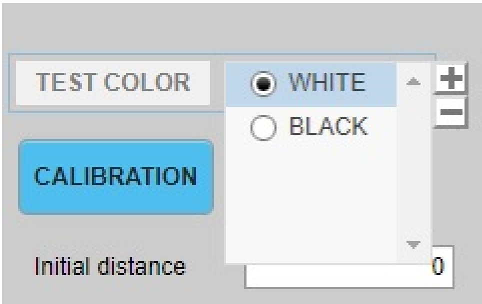


Figure 39: Colour selection tab

6.5.3.2 Calibration

This is used to set up the experiment and position the camera initially, when clicked on the button a new window comes in which the camera video preview opens up, where the user can move the camera position, correct the focus, check the blob position, back ground lighting and contrast. This is an important and necessary function as it calculates the distance between the blobs and automatically fills in the “Initial Distance” column in main page. The trigger code can be seen in the picture below. The camera doesn’t need to be calibrated as such or require any external jigs to measure the distance between blobs, as the percentage change is taken to find the distance between the blobs and not the metric value. But in case if any user needs to find the pixel distance or need to calibrate the camera for some reason the calibration code and jig model can be found in the github site. This button is provided so as to initialise the starting strain measurement to 0.

6.5.3.3 Close CAM

Close cam button is to just to close any camera window that is open which includes preview or calibration window.

6.5.3.4 Area

The cross section area is required to be measured and input manually for calculation of engineering stress.

$$Stress = Force/Area \tag{2}$$

where, Area is the product of initial width (b) and thickness (h) of a test specimen,

$$Area = b \cdot h \tag{3}$$

6.5.3.5 Start Test

The start test button initializes the whole machine by setting the values from calibration and cross section area. See Figure 40.

```
start(app.vid)
trigger(app.vid);
app.vid.LoggingMode = 'memory';
subplot(2,2,1);
h.plot = plot(NaN,NaN,'o'); hold on;
h.meanPlot = plot(NaN,NaN,'-b');
data.X = [];
data.Y = [];
data.Xm = [];
data.Ym = [];
xlabel('strain')
ylabel('stress')
fprintf(app.s,'%s','M'); %initialising manual mode
app.Area = app.AREA.Value;
app.D1 = abs(app.D);
while app.condition

    app.frame = getsnapshot(app.vid);
    app.diff_im =  imsubtract(app.frame(:,:,1), rgb2gray(app.frame));%
    newframe = im2bw(app.frame);
    if app.color == 0
        newframe1 = imcomplement(newframe);
    else
        newframe1=newframe;
    end
    [centroid, bbox] = app.blobAnalysis(newframe1);
    centroid = double(centroid); % Convert the centroids into Integer for further steps

    app.frame = insertShape(app.frame,'Rectangle', bbox, 'Color', 'green');
    subplot(2,1,2),imshow(app.frame);
    numblobs = size(bbox, 1);

    if numblobs>=1
        axis on;
        hold on;
        caption = sprintf('%d blobs found in frame', numblobs);
        title(caption, 'FontSize', 10);
        for i = 1 :numblobs
            cX = centroid(i,1); %x-coordinates of the points
            cY =centroid(i,2); %y-coordinates  of points
            app.hplot= plot(cX,cY,'y+' ,'MarkerSize', 5, 'LineWidth', 2);
            app.hText = text(cX, cY,strcat('X:',num2str(round(cX)),'Y:',num2str(round(cY))));
            for j =1

                X(i,j) =[round(cX)];
            end
        end
        app.Dis = X(1,:) -X(end,:); %difference in point distance

        app.distance = (abs(app.Dis)-app.D1)/app.D1; %strain calculation in percentage
        hold off

    end
```

Figure 40: Test initialising code

6.5.3.6 Tension and Compression User Interface controls (UI controls)

After initialising necessary data, it is required to select the type of test, for which, tension and compression User Interface controls(UI controls) are provided. When one of these buttons are clicked, it begins the test chosen and the relevant graph will come on the left side of the GUI screen with live feed of blob tracking image at the bottom section. The live values for young's modulus (in MPa) and maximum stress (in Mpa) will also be displayed.

6.5.3.7 Manual Mode

If the user is required to move or adjust the center member, lead screw the manual mode is used, which allows the user to control the lead screw rotation using a push button. It can also has the property of changing the speed mode and can also be used as a physical emergency stop button. If one of the push User Interface controls(UI controls) is pressed while one of the programs(tensile or compressive) is running, it will cause the program to be on hold and stop the machine and will automatically jump to manual mode. The manual mode can also be used to do the do the experiments manually instead of running on the automated programs. See Figure 41.

Figure 41: Manual Mode User Interface controls(UI controls)

Stop Machine

In case of emergencies or if the machine is required to stop in the middle of an experiment while it is running the Stop Machine button (UI control) can be used. When pushed, all the current running programs will be terminated.

Figure 42: Code for Stopping the machine

```
% Button pushed function: STOPMACHINEButton
function STOPMACHINEButtonPushed(app, event)
    fprintf(app.s,'%s','Stop');
end
```

Another added feature is in the code through which the machine stops when the test piece breaks and the load becomes 20% less than the total value.

Algorithm 5 Code to automatically terminate the program after getting the result

```
  if F >= app.Fmax,
app.Fmax = F;
end if F < app.Fmax * 0.8 && F>0
app.STRESS.Value = app.maxstress;
msgbox('bye');
return;
end
```

When the experiment is complete and when it stops the final value of “E” will be displayed on the GUI main page. the graph and test piece position is displayed along side this.

6.6 Final Product

The different stages of building can be seen below, see Figure 43. After the completion of each stage the build was evaluated and necessary changes were made on the go to make it as functional as possible. Test requirements used for protype such as test speed was set to 2mm/min and the grippers used are self-centring and does not prematurely cause any fractures with the clamping force. Chances for slipping were minimised by proper tightening of gripper jaws but at times slippage during tests were detected. Values obtained from such cases were discarded. Gauge length: The gauge length are basically points marked by hand on the test specimen, as per standards the gauge length was kept to 50mm[22].

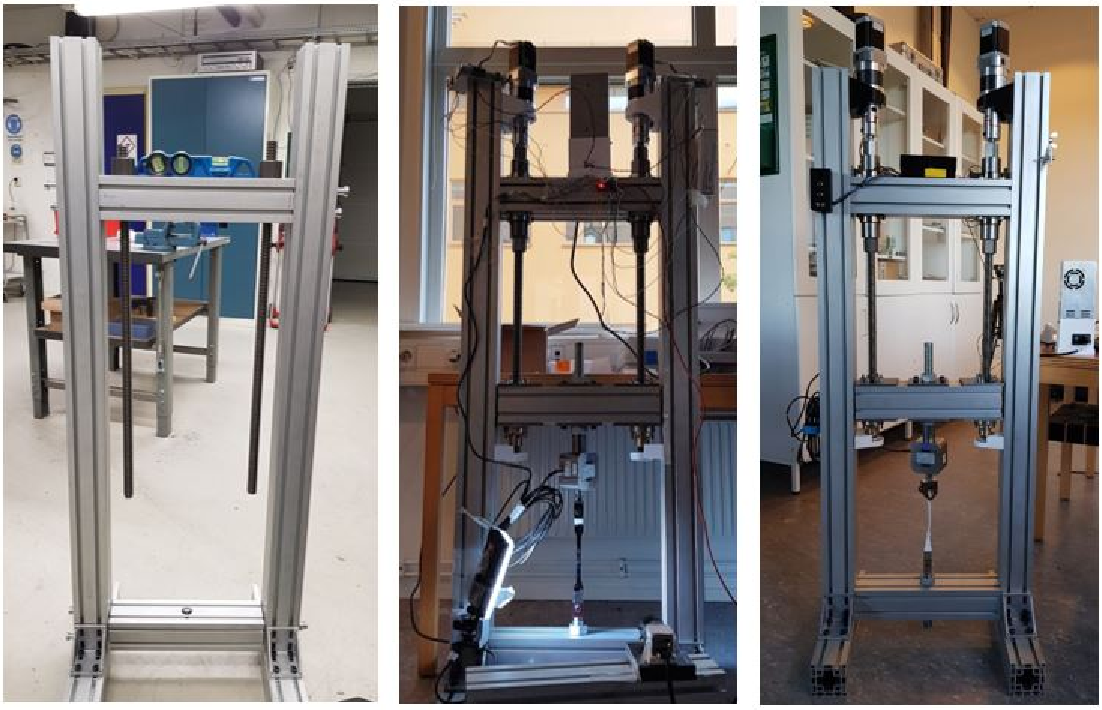


Figure 43: Initial assembly > Testing Phase > Final product

6.6.1 Working Video

The video links for the working of Machine can be found in the links below:

The MATLAB GUI and its working can be seen in Figure 44.

Machine working on GUI [5],test Set up [6]and additional working videos[7] are all available online.

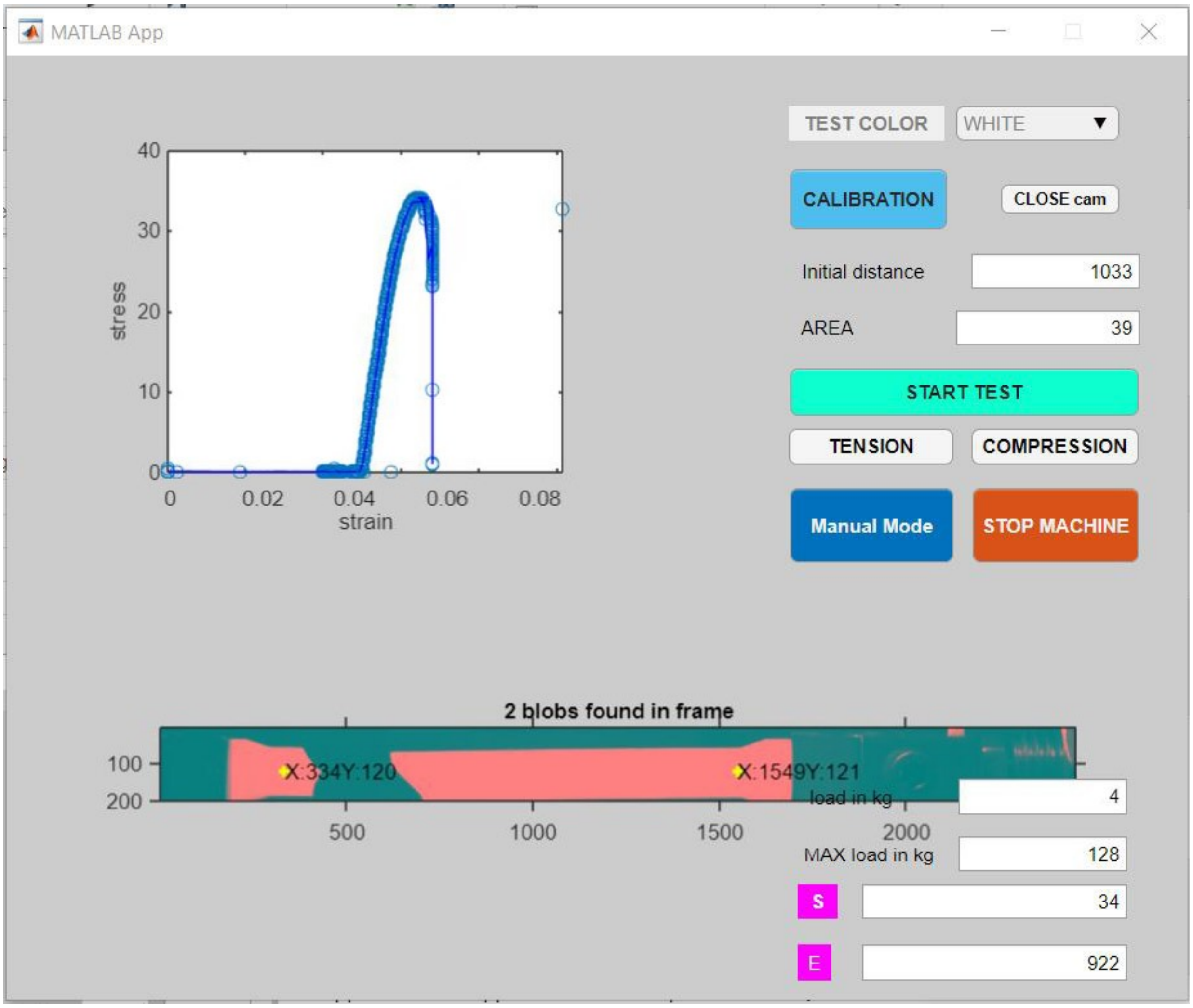


Figure 44: Load graph generated by MATLAB for test on UTM

[5]https://www.youtube.com/watch?v=J8qjTkPQZKw

[6]https://www.youtube.com/watch?v=_CToBMy0ZGI

[7]https://www.youtube.com/user/axcelatommarvelmansi/videos

6.7 Comparison for Accuracy

6.7.1 Setting up of Standard UTM for comparison testing

For comparison on the accuracy of the machine the material chosen was PLA (Polylactic Acid). The Dog bone model was designed using Solidworks according to ASTM (American Society for Testing and Materials) standards type 1 samples, the detailed dimensions for the design and other details can be found in appendix 9.9[5][36].

The designed model was 3D printed using Prusa MK3 printer, the settings used for the printing is as shown in Figure 45. The infill pattern used was rectilinear with 100% infill.

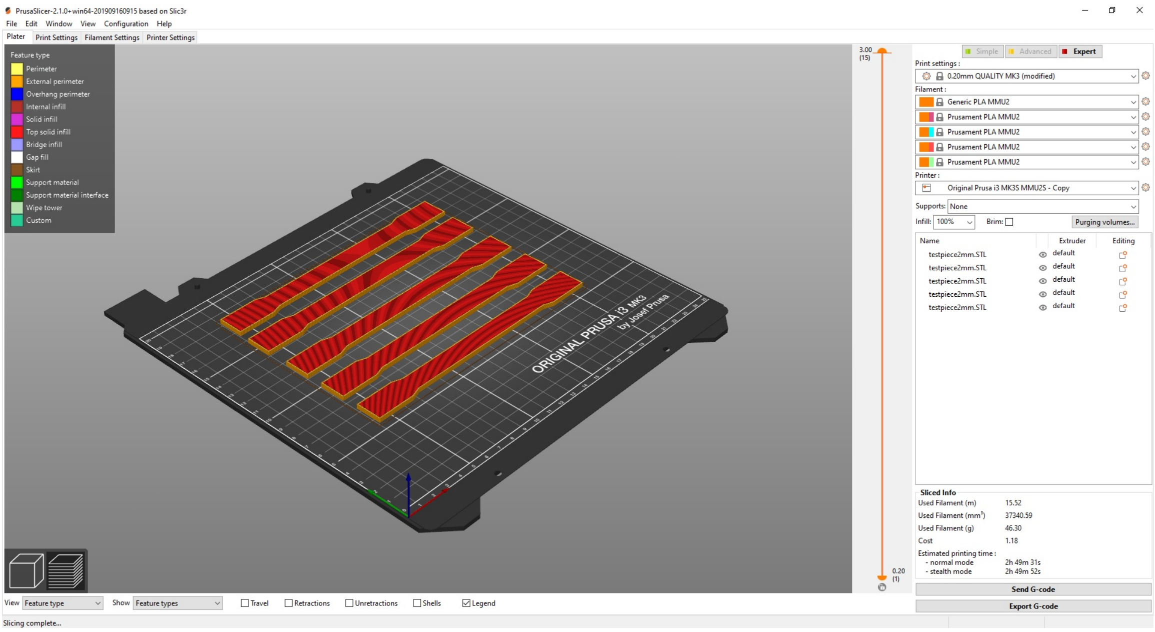
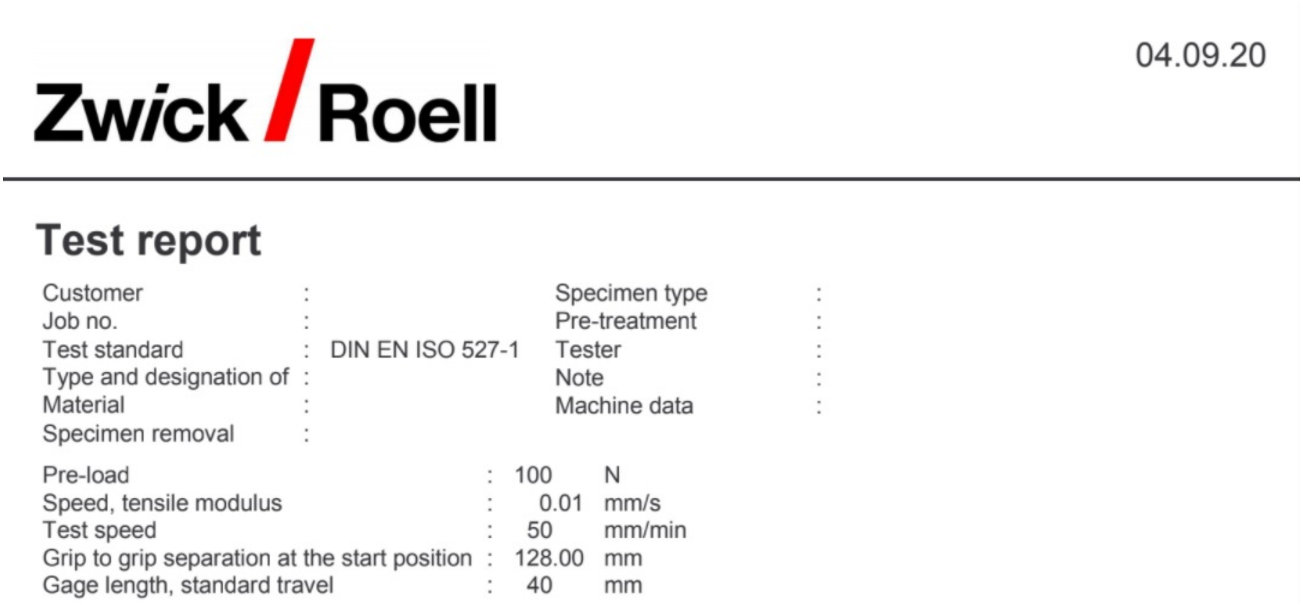


Figure 45: Print settings

The obtained values were compared against Zwick / Roell UTM at JTH with the settings as shown in the Figure 46 below:



Zwick / Roell

04.09.20

Test report

Customer	:	Specimen type	:
Job no.	:	Pre-treatment	:
Test standard	: DIN EN ISO 527-1	Tester	:
Type and designation of	:	Note	:
Material	:	Machine data	:
Specimen removal	:		

Pre-load	:	100	N
Speed, tensile modulus	:	0.01	mm/s
Test speed	:	50	mm/min
Grip to grip separation at the start position	:	128.00	mm
Gage length, standard travel	:	40	mm

Figure 46: Zwick / Roell test settings

The Zwick/Roell UTM [18] uses a 100kN load cell (ISO 7500-1) and a laserXtens (ISO 9513) non-contact extensometer, which are periodically caliberated under their respective ISO (international Organization for Standardization) standards.

As the current printed samples were too thin for the standard test machine to register any values, the results were compared against previously done tests for the same material test pieces created using ASTM standards type 3 samples, the dimension details for the dog-bone design can be found in appendix 9.9[5][36]. In each case multiple tests were conducted, but for the comparison only five samples were considered.

6.7.2 Comparison

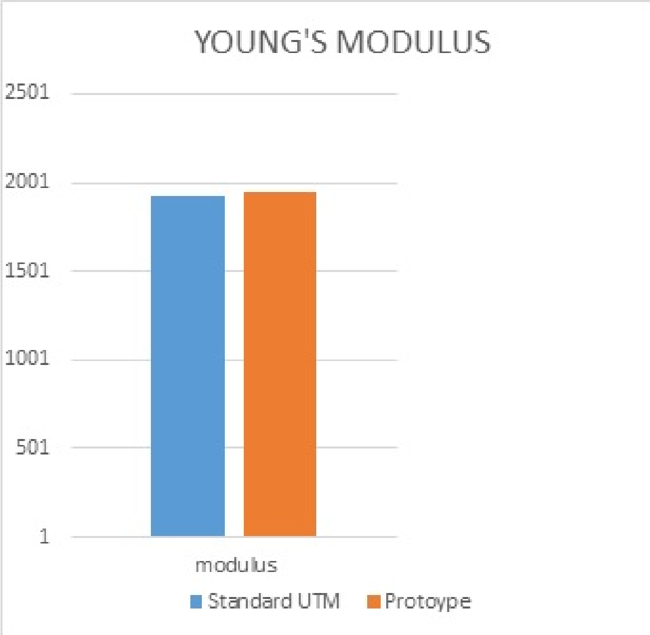


Figure 47: Young's Modulus comparison bar chart

Five test samples were tensile tested in the prototype machine to obtain the stress strain graph and the respective physical properties. Test specimen was 3D printed as per ASTM type1 standards. Loads were applied until failure, the highest being 1372N and lowest being 1215.2 N. The maximum tensile stress of 41.8Mpa and modulus of 1951MPa were obtained. The test method chosen for this project was similar to the experiments done by other researchers and publications[37]. The obtained values also match with the tensile strengths obtained in other publications. [37]

Same procedure was done with the industrial UTM with a test piece of ASTM D368 type3 standard, the maximum tensile stress was around 46.3MPa, and 1930Mpa. The compared overall results gave an absolute difference of 21Mpa, see Figure 47, and shows a relative difference of 2%. But the values may vary under different printing and orientation conditions.

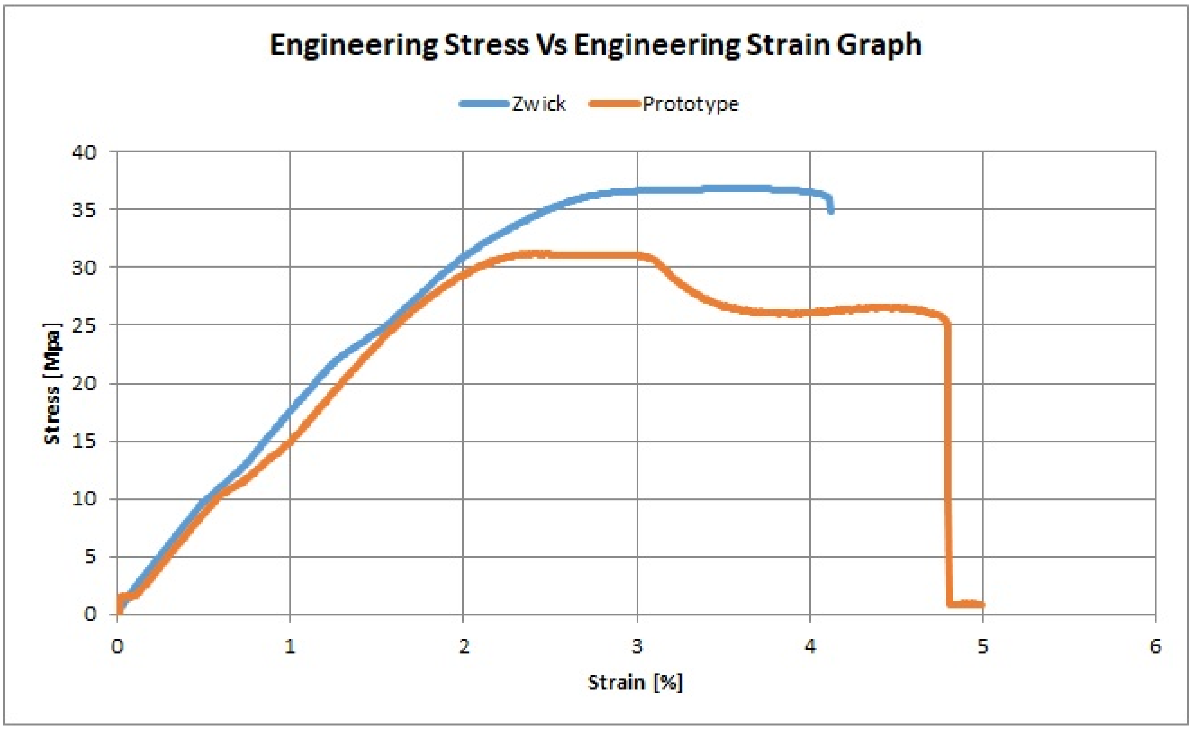


Figure 48: Comparison of Prototype and Zwick/roel UTM

The respective graphs from one of the tensile test results are shown in Figure 48. As the feature for automatic stop for the prototype was removed , all points were plotted even after the failure of test piece. This graph shows its yield point without a stress increase after yielding. Whereas, the resulting graph obtained from the industrial UTM stops after a set gauge length or failure.

The values obtained between the two test results provides a similar modulus but a small dip can be seen between the ultimate tensile strengths of the two test results, due to the following reasons:

- One reason may be due to different displacement rate of the two machines, as the strength measured in a faster displacement rate shows a higher strength measurement than in a slower displacement rate.

Table 6. Filament Tensile Testing

Displacement Rate (mm/min)	Ultimate Stress (MPa)	Ultimate Strain (%)	Modulus of Elasticity (GPa)
500	60.86	12.3%	1.78
500	59.41	14.3%	1.72
500	63.44	9.3%	1.77
500	56.89	4.6%	1.89
500	54.17	5.5%	1.73
200	61.10	16.9%	1.93
200	59.22	14.6%	1.89
200	58.95	12.4%	1.81
200	60.26	11.0%	1.89
200	58.05	11.8%	1.83
50	56.25	16.2%	1.54
50	53.40	20.4%	1.50
50	56.08	14.5%	1.66
50	55.67	8.2%	2.02
50	52.16	28.5%	1.46
5	48.25	24.6%	1.34
5	47.01	14.4%	1.27
5	48.62	12.1%	1.16
5	48.67	21.4%	1.35
5	48.62	7.6%	1.43

Figure 49: tensile tested results of PLA for varying displacement rates from reference research paper [24]

The displacement rate of the prototype machine was 2mm/min (as per DIN EN ISO 527-1)[22].Whereas the zwick/roell (industrial UTM) was 50mm/min. Hence the values of ultimate stress may vary with slightly lesser values obtained with slower displacement rates. For the 100KN UTM a larger test piece of ASTM D638 type 3 was used.

- Even though, the difference in section thickness is claimed to show negligible variation in strength values as per standards, the difference in specimen geometry does slightly effect in the tensile property of the material, as found in the research paper.

- Polymers being 3D printed specimens show variations in strength with printing orientation and infill[34]. Unlike metals polymers have many other factors to consider. Use of 3D printed specimen for comparison between the two machines are not much reliable in this case[9].

7 Discussion

The initial proposed design required a few alterations to be made while machining and manufacturing due to various constrains. But all the alterations and changes were made in such a way that it did not affect the structural integrity of the machine or changed any requirement sets for it at the beginning.

The initially proposed design had a new clamp design which was self centering and has better theoretical gripping power, but due to technical limitations and availability of materials, a pre-machined clamp that was already available was used.

The Lead screw height is limited to a fixed value, therefore machine height and length in which the center member can move cannot be changed.

When the machine is working the lock nut sets have a tendency to become displaced due to vibration of the lead screw. 3D printed washers are used to to keep the nuts and ball bearing in place to avoid unnecessary contact and wear.

Due to the continuous vibration of lead screw and back lash, the bottom round and hexagonal nut set tends to get loose and move down. The issue was rectified by taping the lead screw section with vibration absorbing tape to form a tight fit.

When the self centering grippers are in line irrespective of what defect it has, the test piece will be centered. But due to the continuous usage, the gripper groves became slightly lose due to which the test piece slipped during tests. This was rectified by using polymer strips in between groves to maintain the steadiness and integrity.

The quality of an experiment is defined as the reliability of the reading obtained during the experiment. That is a steady movement in terms of the values obtained. The experiment quality is improved by the use of pre-machined self centering grippers as they do not require constant calibration. The use of stepper motor and arduino connections further adds the improvement in precise positioning of lead screw and speed control. With the implementation of Graphical User Interface and MATLAB coding the machine system is completely functional in any available computer systems without needing additional software with no compatibility issues.

When comparing the values obtained from test machine and standard UTM (Zwick /Roell) it was found to be in the similar value ranges.

A few bugs were found in the graph generation code of which some were debugged. Even though some bugs are still present in the code the machine is functional with the capability of forming graphs with relative accuracy. Further upgrades and debugging is possible which are beyond our capability.

8 Conclusion and Future work

In the modern age of 3D printing it is not logical or feasible to have UTM with a load capacity like 10kN which costs 21,000 USD[15] which is approximately 196,567 SEK to test the material properties of polymers. Keeping this in mind, the team decided to find a way to circumvent the cost issue by constructing a UTM which required minimal machining and by using readily available materials. This thesis has helped to achieve an alternate to commercially available UTM for polymers, which is modular and customisable. All the designs and related programmed codes will be available to the public through Github, for further feedback and upgrades[8].

The second major achievement of the thesis is the integration of Real-Time Object Detection and Tracking technology into the UTM, using a high resolution camera to measure the strain instead of a conventional extensometer. It is also established that MATLAB is viable to be used to create the Graphical User Interface and to code the working of the machine. Furthermore, all the requirements set for the machine at the start of the thesis work have been met.

According to ISO standards grips for holding the test specimen shall be attached to the machine so that the major axis of the test specimen coincides with the direction of extension through the center line of the grip assembly[22]. Since a pre-machined in-line gripper is used, which self centers (compared to a two sided screw action grips), it minimises the need for frequent centering and in-line calibration.

With the implementation of a graphical user interface (GUI) system, increases the reliability of the machine and opens the option to make it upgradable.

The feasibility of this machine for actual testing was confirmed by comparison of values obtained from several sample tests conducted on both prototype test machine and zwick/roell UTM, as

the modulus values obtained in both machines were found to be close.

From the stress-strain graph obtained it was concluded that 3D printed test samples are not extremely reliable to access the accurate values through tensile testing as there are way too many factors affecting the structural integrity of the test piece. For proper comparison values material with isotropic nature are preferable.

Future-work

With the machine being modular the parts can be swapped out with ease making upgrading possible. In the future with the proper components and electric motor the machine can be upgraded to perform fast testing. By swapping the gripper / adapters various tests like compression test and three point bending test can also be conducted. The machine can be further upgraded to simultaneously test multiple test pieces or samples at the same time. The machine can also be upgraded to perform shear testing and to evaluate true stress by using the high resolution camera and proper MATLAB algorithm.

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9 Appendix

9.1 Load cell Specification DATA sheet

TT

SCELL

GENERAL TECHNICAL CHARACTERISTICS FOR g= 9,8031 m/ s²			
OIML Class		C3	UNITS
Divisions n_{LC}		3000	
Minimum Dead load E_{min}		0	kg
Z= E_{max} / 2DR		3000	
Y= E max./ Vmin.		10000	
Rated Capacity E_{max}		2000 - 5000 - 10000	kg
Rated Sensitivity C		2 ± 10 %	mV/V
Rated Input Voltage		10	V dc
Input Voltage Range		5...15	V ac/dc
Input Resistance R_{LC}		1000 ± 110	Ω
Output Resistance		1000 ± 10	Ω
Zero Balance		± 2	% Emax
Insulation Resistance at 50 V DC		> 5000	MΩ
Service Overload		> 150	% Emax
Overload Limit		> 300	% Emax
Temperature Range	: Compensated	- 10 ... 40	°C
	: Operating	- 30 ... 85	°C
	: Storage	- 30 ... 90	°C
Max. Nonlinearity		0,02	% Emax
Max. Hysteresis		0,02	% Emax
Max. No repeatability		0,01	% Emax
M Max. Creep in 4 hours		0,03	% Emax
Max. Zero Recovery Test in ½ hour		0,02	% Emax
Max Temperature effect	: On Sensitivity	0,02	% Emax / °C
	: On Zero	0,02	% Emax / °C
Weight		2000 (2000kg - 5000kg) 2500 (10000kg)	g
Cable Length		5	m
Environmental Protection		IP67 - DIN 40050	

9.2 Digital camera and its specifications DATA sheet

Sensor

Sensor Vendor	Sony
Sensor	IMX264
Shutter	Global Shutter
Max. Image Circle	2/3"
Sensor Type	CMOS
Sensor Size	8.4 mm x 7.1 mm
Resolution (HxV)	2448 px x 2048 px
Resolution	5 MP
Pixel Size (H x V)	3.45 µm x 3.45 µm
Frame Rate	35 fps
Mono/Color	Mono

EMVA Data

EMVA Quantum Efficiency (typical)	68.0 %
Dark Noise (typical)	2.3 e^-
Saturation Capacity (typical)	10.5 ke^-
Dynamic Range (typical)	73.4 dB
Signal-to-Noise Ratio (typical)	40.2 dB

Camera Data

Interface	USB 3.0
Pixel Bit Depth	10 or 12 bits
Synchronization	• software trigger • hardware trigger • free-run
Exposure Control	• programmable via the camera API • hardware trigger
Digital Input	1
Digital Output	1
General Purpose I/O	2
Power Requirements	• Via USB 3.0 interface
Power Consumption (typical)	2.5 W

9.3 Torque Calculations

Raising the load

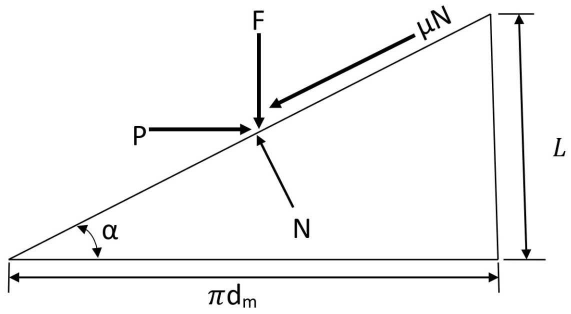


Figure 50: Forces at the contact surface for raising the load

α is the helix angle,
P is the axial force acting on the lead screw,
N is the normal reaction and μN is the frictional force.
d_m is the mean diameter of the thread

$$F = 5000N$$

$$\alpha = tan^{-1}(\frac{L}{\pi d_m}) = 1.657$$

For equilibrium

$$\Sigma x : P - \mu N cos\alpha - N sin\alpha = 0$$

$$\Sigma y : F + \mu N sin\alpha - N cos\alpha = 0$$

This gives:

$$P = \frac{F(\mu cos\alpha + sin\alpha)}{(cos\alpha - \mu sin\alpha)} = 897.909N$$

Torque transmitted to rise the load

$$T = P \times \frac{d_m}{2} = 897.91 \times 11 = 9877.01Nmm = 9.88Nm$$

Lowering the load

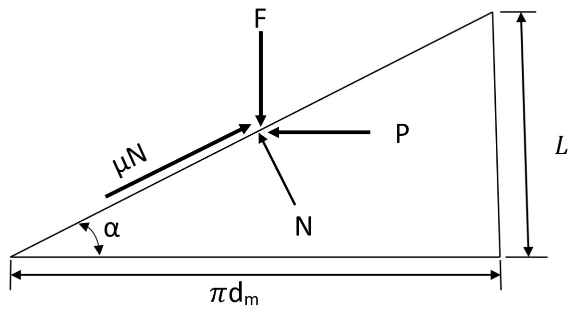


Figure 51: Forces at the contact surface for lowering the load

$$F = 5000N$$

For Equilibrium,

$$\Sigma x : P - \mu N Cos\alpha + N Sin\alpha = 0$$

$$\Sigma y : F - N\alpha – \mu N Sin\alpha = 0$$

This gives

$$P = \frac{F(\mu Cos\alpha - Sin\alpha)}{(Cos\alpha - \mu Sin\alpha)}$$

Torque to lower the Load

$$T = P \times \frac{d_m}{2} = 6060Nmm = 0.6Nm$$

9.4 Planetary Gearbox DATA Sheet

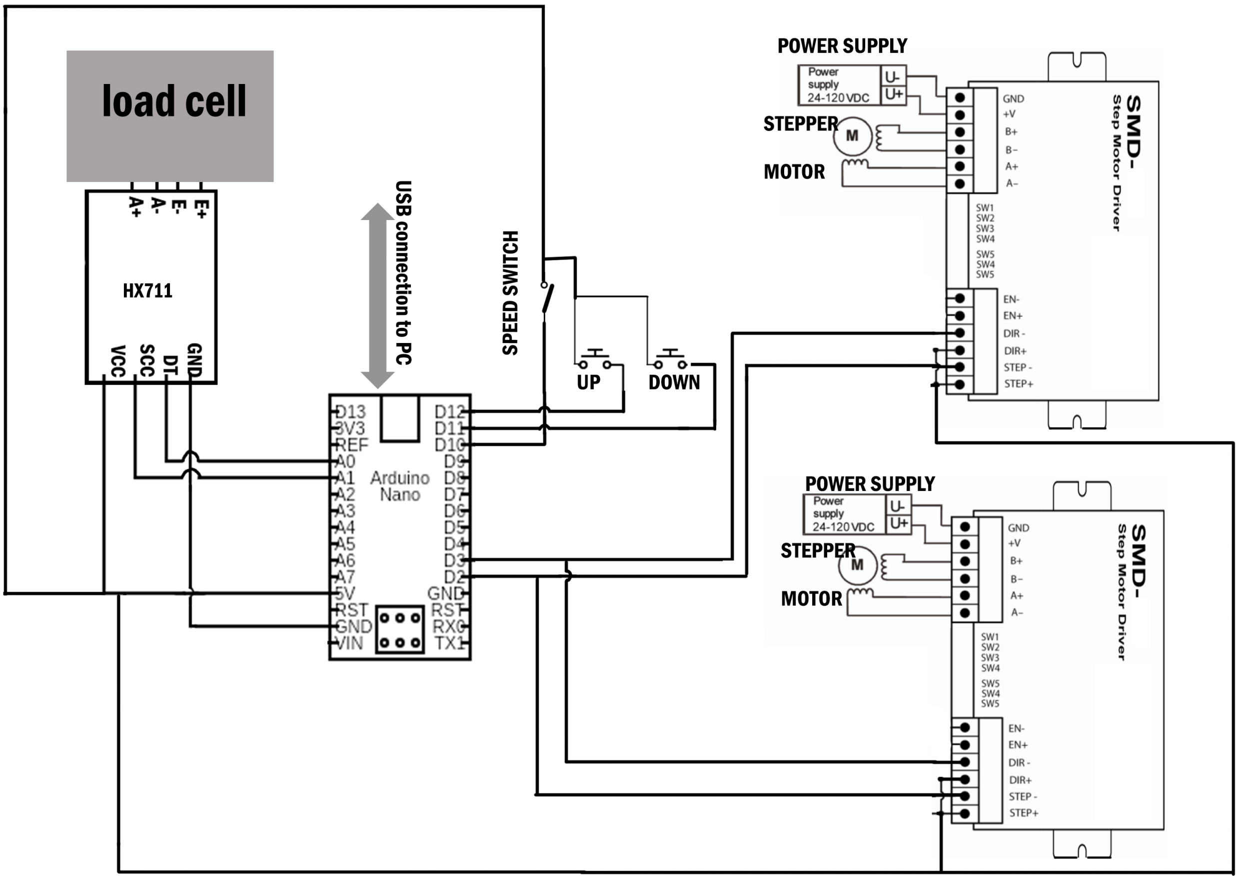
		EPL-Q 64	EPL-Q 84	EPL-Q 118
ratio i =		3 - 1000	3 - 1000	3 - 1000
max. torque [Nm]		55	125	255
backlash [arcmin]	standard	≤ 10	≤ 10	≤ 8
	reduced	≤ 7	≤ 6	≤ 6
output shaft load	radial load	1000 N	2500 N	3500 N
	axial load	1200 N	2800 N	2800 N

type	ratio	nominal output torque [Nm] 1)	max. acceleration torque [Nm] 2)	emergency torque [Nm] 3)
EPL-Q 64	3	20	36	72
	4 / 5 / 7	26	44	84
	10	16	24	62
	12	36	45	72
	16 / 20 / 40 / 70	42	52	84
	25 / 35 / 50	44	55	84
	100	18	28	62
	120 / 160 / 200	42	52	84
	250 / 350 / 500	44	55	84
	700	42	52	84
	1000	25	28	62

9.5 Stepper motor control

```
#include <Stepper.h>
const int stepsPerRevolution = 200;
// change this to fit the number of steps per revolution
// initialize the stepper library on pins 8 through 11:
Stepper myStepper(stepsPerRevolution, 2, 3);
void setup()
{
// set the speed at 1000 rpm:
myStepper.setSpeed(1000);
// initialize the serial port:
Serial.begin(9600);
}
void loop()
{
// step one revolution in one direction:
Serial.println("clockwise");
myStepper.step(stepsPerRevolution);
delayMicroseconds(100);
// step one revolution in the other direction:
Serial.println("counterclockwise");
myStepper.step(-stepsPerRevolution);
delay(500);
}
```

9.6 Circuit Diagram

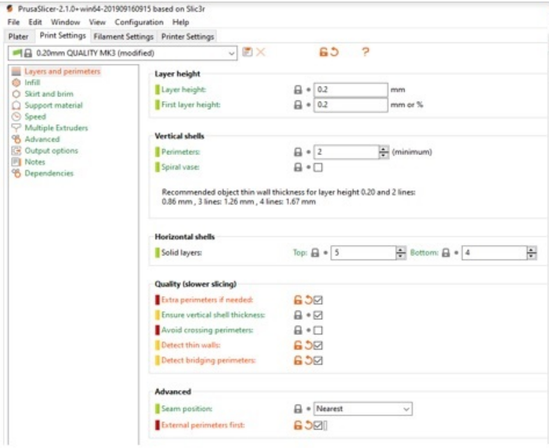


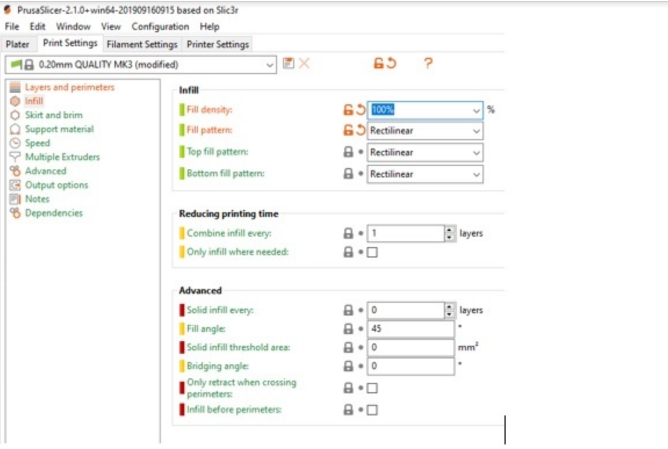
9.7 Code for calibration button

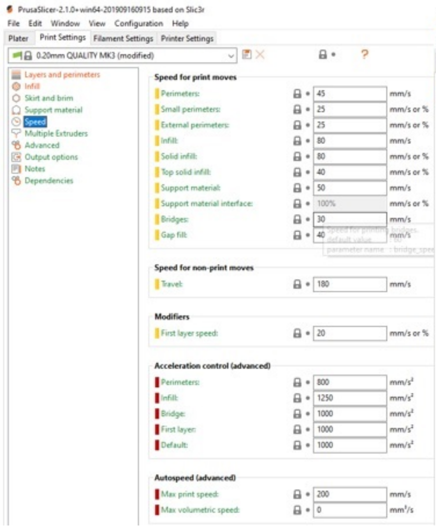
```
        % Button pushed function: CALIBRATIONButton
        function CALIBRATIONButtonPushed(app, event)
 app.vid = videoinput('winvideo', 2, 'Y800_2456x2052'); %(creating vid inputobj(adaptorname, deviceID,vidformat) ...
                                                        %if error comes while detecting, go to apps/image aquisition/tools/refresh)
app.vid.ROIPosition = [0 951 2456 200];
triggerconfig(app.vid, 'manual');
% %vid.FramesPerTrigger  = inf'; %camera framerate persec x time for viewing
app.vid.FrameGrabInterval = 2; %time taken to log in the data

app.pointTracker = vision.PointTracker('MaxBidirectionalError', 2);
app.blobAnalysis = vision.BlobAnalysis('AreaOutputPort', false, ... % Set blob analysis handling
    'CentroidOutputPort', true, ...
    'BoundingBoxOutputPort', true', ...
    'MinimumBlobArea', 100, ...
    'MaximumBlobArea', 1000, ...
    'MaximumCount', 8);

preview(app.vid);
%
start(app.vid)
trigger(app.vid);
app.vid.LoggingMode = 'memory';
```

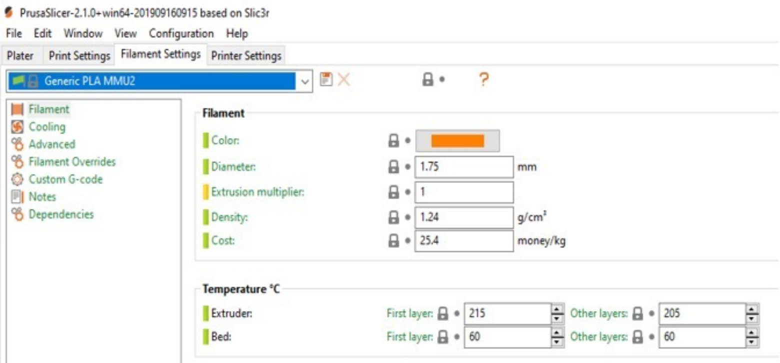
Figure 52: Code for calibration button

9.8 Detailed settings for 3D printer









9.9 ASTM Standards for samples

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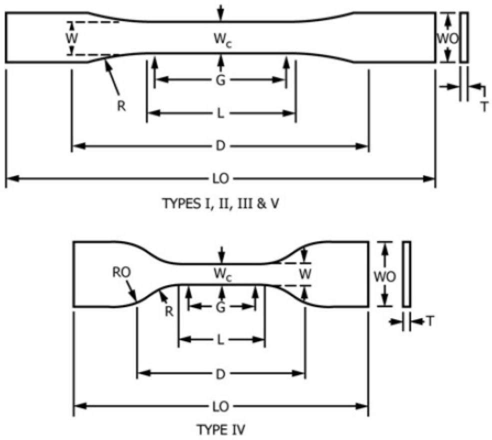

Specimen Dimensions for Thickness, *T*, mm (in.)[A]

Dimensions (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
L—Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02)[C]
WO—Width overall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)
WO—Width overall, min[G]	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)
LO—Length overall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
G—Gage length[I]	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010)[C]
G—Gage length[I]	...	...	...	25 (1.00)	...	±0.13 (±0.005)
D—Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
R—Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
RO—Outer radius (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)