DEVELOPMENT OF A PORTABLE LOW STRAIN RATE TESTING MACHINE

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ABSTRAK

Ujian kadar terikan perlahan, adalah penting dalam memahami kelakuan mekanikal bahan. Ia memerlukan penggunaan regangan dinamik perlahan dengan kadar lanjutan yang berterusan pada spesimen. Mesin Tegangan Universal (UTM) biasa boleh digunakan untuk menentukan kadar terikan bahan. Walau bagaimanapun, mesin yang boleh menggabungkan ujian kadar terikan rendah dan tinggi pada kos yang berpatutan biasanya tidak mudah diakses. Oleh itu, kertas kerja ini cuba mencadangkan reka bentuk konsep yang boleh digunakan dalam mesin ujian kadar terikan tinggi serta secara bebas menjalankan ujian kadar terikan rendah. Komponen kritikal seperti pemegang nat spring, batang penarik, pemegang cengkaman bergerak dan pemegang cengkaman pegun telah direka dan dibuat. Manakala bingkai yang memegang komponen ini pada tempatnya telah digunakan semula dari bahagian mesin. Ujian telah dilakukan untuk mengesahkan bahawa prototaip boleh berfungsi seperti yang dimaksudkan dengan membandingkan keputusan dengan mesin UTM Gunt. Lengkung lanjutan kedua-dua mesin dan prototaip adalah serupa dan prototaip adalah tegar (tidak mengalami lenturan yang ketara semasa ujian). Akhir sekali, satu skim bagi menyambung ke mesin SHPB untuk membolehkan keupayaan ujian terikan tinggi dan terikan rendah pada persediaan SHPB unik telah dicadangkan.

ABSTRACT

Slow strain rate testing, is important in understanding the mechanical behaviour of material. It entails applying a slow dynamic strain with a constant extension rate to a specimen. Typical Universal Tensile Machine (UTM) can be used to determine the strain rate of a material. However, a machine that can couple low and high strain rate testing at a reasonable cost is usually not easily accessible. Therefore, this paper attempts to propose a design of concept that can be used in a high strain rate testing machine as well as to independently conduct low strain rate testing. Critical components such as the spring nut holder, pulling rod, moving grip holder and stationary grip holder were designed and fabricated. Whereas the frame which holds these components in place was reused from the machine part. A testing was done to verify that the prototype can perform as it is intended by comparing results with a UTM Gunt machine. The extension curve of the both machine and prototype were similar and the prototype was rigid (did not endure significant bending during the test). Finally, a scheme to connect to a SHPB machine to allow high strain and low strain testing capability on a unique SHPB setup was proposed.

CHAPTER 1

INTRODUCTION

1.1 Research Background

A low strain rate testing is essentially stress test where tensile force is applied on a specimen that is slowly extended at a uniform strain rate until the occurrence of fracture [1]. The ISO 6892-1:2016 "Metallic materials - Tensile testing, Part 1: Method of test at room temperature" [2] and ASTM E8/E8M-16a "Standard Test Methods for Tension Testing of Metallic Materials" [3] are the two relevant international standards for determining tensile properties. According to these two standards, tensile testing for the material characteristics mentioned above should be performed at strain rates ranging from 10^{-5} s^{-1} to 10^{-3} s^{-1}, depending on the material characteristic and test technique utilised [4]. Low strain rate tensile property measurements are important in characterization of materials for a variety of technical applications.

Tensometer is a device that measures the properties of tensile of materials, such as Young's Modulus and tensile strength. The equipment is powered by either a driving a screw or a hydraulic ram which has the abibilty to construct far more complex loading patterns, such as the cyclical loads required for fatigue strength testing. Environmental chambers can be added to this machine to allow for testing at varying temperatures or humidity levels, for example [5].

Hounsfield/Monsanto Tensometer is a tensile testing machine which is used to conduct tensile test on specimens specifically with a low strain rate. A sample is put between two grips that are manually or automatically adjusted to provide force to the specimen. When flat sheet is being tested, the material must be cut to a precise shape to suit the grips, which is commonly in the form of a dog-bone shape. The sheet is cut or machined to shape, and a smooth edge requires tremendous attention. If faults are not repaired, they may cause premature failure, resulting in an underestimation of tensile strength [6]. In this project, a portable Tensometer which is a low strain rate testing machine that can operate independently or coupled to a Split Hopkinson Pressure Bar machine is proposed.

This machine can be manually or electrically operated. Despite having different means of operation, the basic working principle of this machine is by firstly placing a specimen in between the two clamps/grips as shown in Figure 1.1. These clamps/grips are firmly locked onto fixed end and the pulling end of the Hounsfield.

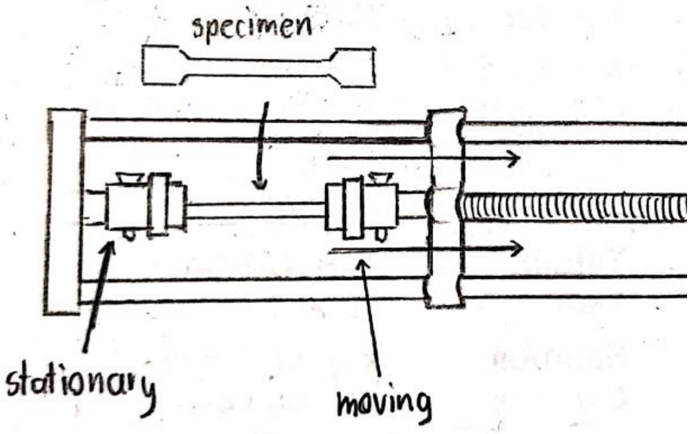


Figure 1.1 Specimen clamping

Once the specimen has been secured, a load can be applied to pull it slowly. The clamps/grips will begin to move away from each other pulling the specimen while applying a low strain rate tensile force on it. The pulling action can be done either by winding a handle manually with the help from a set of reducing gear or by just simply having and electrical motor to do the work. The motion of the pulling force is shown in Figure 1.2.

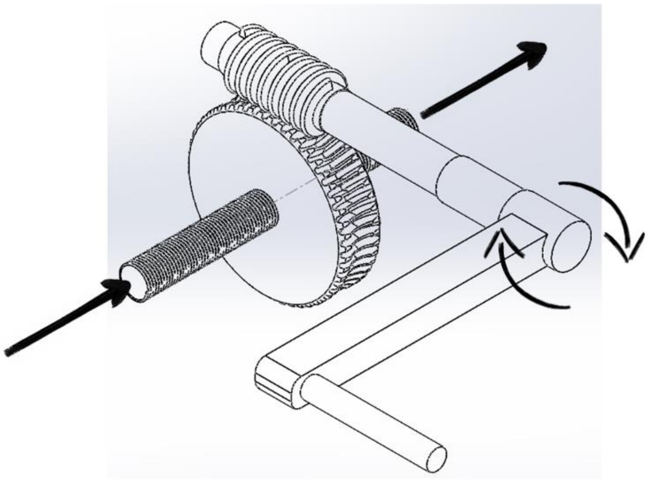


Figure 1.2 Motion of action

Initially, the objective of this project was that the finished fabrication of this machine will allow the testing of specimen in a wide range of strain rate. For example, when high strain rate test is to be carried out, specimens will be placed in between the clamps of the SHPB machine and when low strain rate test is to be carried out, the specimen will be placed in between the clamps of the Hounsfield Tensometer. As a result, this whole machine will become a low-cost hybrid of Hopkinson and Hounsfield technology.

1.2 Problem Statement

The current limitation of SHPB machine available in the Applied Mechanics laboratory of Mechanical Engineering school has the ability to provide strain rate with a range of $600s^{-1}$ to $1000s^{-1}$.

However, there is a need for the machine to have a low strain rate testing capability for testing materials at wider range of strain rates. An independent Hounsfield tensometer is not commonly available and are quite costly. Hence, a hybrid has to be developed by incorporating a Hounsfield tensometer with the current SPHB machine in lab to add low strain rate testing with a range of 0.00001s^{-1} to 600s^{-1}.

1.3 Objectives

The specific objectives of this research are:

1. To develop a hybrid Hounsfield and Hopkinson for testing materials at a wide range of strain rates.
2. To test and verify the results obtained when using the developed machine.

1.4 Scope of Research

This project will be focusing on two things which are simulation and experimental. Simulation in terms of designing model using CAD software and experimental in terms of experimenting with the fabrication and carrying out tests using the machine. The scopes of this project include, planning the project outputs based on a schedule. A schedule was created to have an organized planning of the things that has to be done. Besides that, researching and learning about Hopkinson and Hounsfield technology and collect as many useful data as possible to be implemented to the design. The pulling mechanism of the tensile tester is the main focus information that must be researched. With all those collected data and information, a working design that measures low strain rate must be proposed. This feature that can carry out low strain rate testing will be added to a currently available high strain rate testing machine. All the fabrication and development will be done within an available budget provided by the school.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to SSRT

The ISO 7539-7 standard describes the slow strain rate testing (SSRT) procedure [7]. For usage in sour service contexts, this approach of determining threshold stress still needs to be validated. Furthermore, its applicability in predicting SSC is up to interpretation (Mack, 2008). SSRT has, however, been effectively used to identify SCC susceptibility and rank families of alloys in other contexts, such as the nuclear and aviation sectors [8].

This slow strain rate testing method, developed by Parkins (1979), entails applying a strain to a specimen at a slow steady rate (typically 10^{-8} to 10^{-4} mm.s^{-1}) until rupture occurs. Metal plasticity, or relative elongation and surface area reduction, is linked to time to failure [9]. SSR testing, which is used as a screening approach, Braun R. (1994), has the benefit of being faster than the old method because the rupture happens in a few tens of hours [10]. The majority of the specimens are smooth. 3 percent NaCl + 0.3 percent H2O2 is the most acceptable solution for this type of test, Holroyd NJ (1982) [11]. This approach is appropriate to aluminium alloys, according to Beavers JA, Koch HG (1994), albeit testing on high-strength aluminium alloys have resulted in categorization deviations Buhl H (1979), Brown AR, Gray JA (1974) [12], [13] & [14].

According to the information collected, there are mostly machines that are capable of testing only high strain rate or only low strain rate. These machines are specialized in only one type of strain rate to be tested particularly. A mixture of high and low strain rate testing machine is much needed nowadays for various reasons. One of the main reasons is that, specimens can be tested in a much wider range of strain rate in a single machine. There will be no need to find for a particular high strain machine for high strain rate testing and low strain machine for low strain rate testing. It will be more convenient and easier to test the specimens. Besides that, different velocity of impact can be applied. Instead of having only one impact velocity in a testing machine for example having high velocity for high impact in SHPB, two different velocities can be applied whenever needed which includes, low velocity for low strain rate. With the low strain rate feature added, it will be able provide impact results for both high and low velocity in a single machine. Even though there are machines that can carry out test in a wider range of strain rate, most of are incredibly expensive and has high maintenance cost. In this project, the low strain rate feature will be added with an available budget which costs much lower.

2.2 Benefit of SSRT

Corrosion Resistant alloys (CRAs) susceptibility to environmentally assisted cracking (EAC) is determined by strain rate. The choice of strain rate, as defined in NACE TM0198, guarantees that the test is adequately discriminating, relatively quick, and has acceptable repeatability and reproducibility. For many systems, including M13Cr steels, a strain rate of $1 \times 10^{-6}\ s^{-1}$ appears to provide sufficient results. When a faster evaluation is required, a strain rate of $4 \times 10^{-6}\ s^{-1}$ can be used. For nickel and austenitic alloys, this strain produces good results. Other systems, on the other hand, may have diminished repeatability and reproducibility as a result (NACE, 2004c) [8].

2.3 Drawback of SSRT

The most common complaint of the SSRT methodology is that specimens are always pushed to failure, making the testing conditions too harsh. Another crucial aspect that has been demonstrated to have a significant impact on SSRT findings is the surface finish (Mack, 2008) [8]. The slow strain rate test is essentially a tensile stress test on a standard smooth tensile specimen that is slowly extended at a constant strain rate until fracture occurs. Strain rates of 10^{-4} to 10^{-7} s^{-1} are usual when the crosshead speed is controlled. Gabb et al. (2014) and Németh et al. (2017) employed the SSRT test to assess the embrittlement of nickel-based superalloys. This process is triggered by a method of environmentally-assisted intergranular cracking and occurs in high strength nickel-based alloys at intermediate temperatures such as 500°–750°C. During SSRT testing at higher temperatures or for more ductile alloys, the time and strain rate dependent deformation behavior of the sample can instead be attributed to creep. This test procedure is then particularly useful for determining short-term creep qualities quickly. It can be difficult to determine the optimum load to apply to a traditional constant load creep test, especially if the creep response of the material is unknown, and there is always the possibility that the test will be either too short or too long, failing to give the data expected [1].

2.4 Hounsfield/Monsanto Tensometer

2.4.1 Introduction

Figure 2.1 Hounsfield Tensometer

The Tensometer tensile testing machine (Monsanto, Swindon, England) is utilized to gather data of stress vs strain for diverse materials. Its simplicity makes it ideal for teaching purposes, and it has long been utilised in dental schools. The original

Monsanto Tensometer Type W displays the applied load at any given time using a mercury column that is followed by an eye, and a chart record is manually created by marking the paper on a drum that is geared to the lead screw. [15].

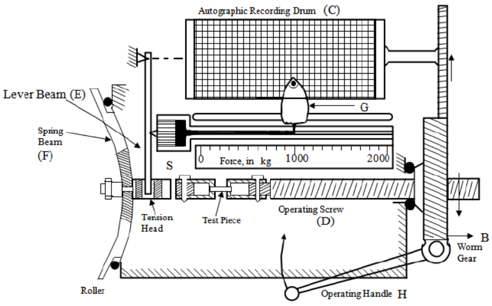


Figure 2.2 Line Diagram of Hounsfield Tensometer

The employment of the mercury method was linked to a variety of issues, including the creation of dross and the inconsistent behavior of the meniscus as a result. The danger posed by mercury intoxication is even more serious. Despite certain new design enhancements intended to mitigate the problems with this model, mercury spillage is an all-too-common occurrence with these machines, and remains a big concern with older equipment. It must be eradicated as a source of danger. As a result, electronic load measurement is a desirable objective.

The lack of a mechanism of calculating cross-head displacement is a second flaw in the Monsanto Tensometer W's design. A constant-speed electric motor system can be used, with location and test results being correlated over time. If a mechanism other than the internally-geared chart drum was adopted, the necessary irregular hand-operation would result in an erratic chart-record. For determining absolute linear displacement, complex systems are available, but the main requirements for a teaching machine are robustness and ease of setup.

The Tensometers utilized in this University's Faculty of Dentistry have been improved in the following ways:

a) The mercury threat was eliminated by replacing it with a linear voltage displacement transducer (L VDT) whose output was proportionate to the applied load and was fed into a chart recorder (Y-axis).

b) The addition of an optical transducer and electrical circuitry resulted in a TTL-compatible pulse train that was applied to the recorder's external chart drive (x-axis) and caused proportional chart transport.

2.4.2 Load Measurement

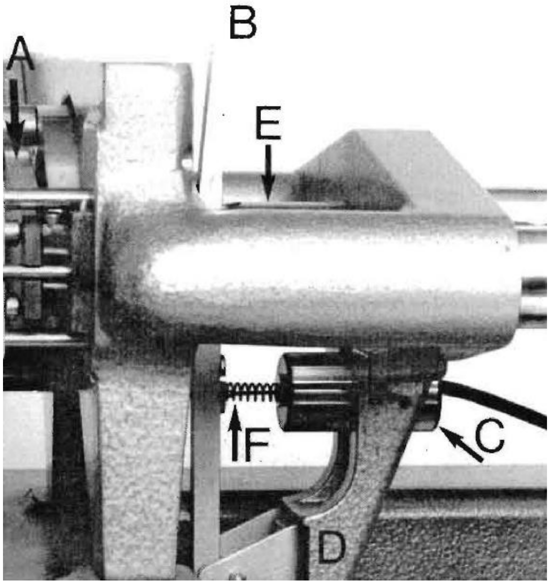


Figure 2.3 Detail of LVDT mounting

The Tensometer's basic load determination element is a 3-point loading replaceable steel beam (part A, Figure 2.3). The complete scale deflection according to the mercury system equated to a displacement of the beam's centre point of 1.3 mm to within the system's precision, as determined by a dial gauge. The mercury-piston was activated by a spring-loaded lever (part B, Figure 2.3), which served as a load-beam follower. The LVDT's core was attached to this lever, with the LVDT itself (part C, Figure 2.3) replacing the mercury-piston, which was removed from the machine along with the remainder of the mercury system, calibration scale, cursor, chart drum, gears, and so on. The remaining parts labelled as D, E and F are yoke, pull rod and LVDT armature push rod and spring respectively.

2.4.3 Displacement

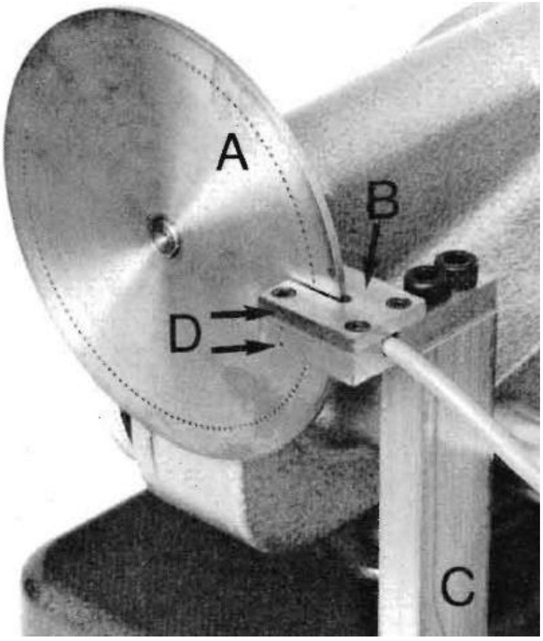


Figure 2.4 Detail of optical transducer mounting

A gear system drives the lead screw that causes displacement of the moving cross-head. A perforated disc (part A, Figure 2.4) with 150 holes of l mm diameter spread evenly around its circumference was carried on a spindle stub ordinarily used for an external motor drive. The manual driving handle rotated at the same rate as this. The disc was connected to an optical transducer (part B, Figure 2.4) with an infrared source and detector. The infrared beam was recognized and a pulse was created at the optical transducer's output when a hole in the disc passed through alignment with the holes in the optical transducer.

2.4.4 Mechanical Design Details

The yoke (part D, Figure 2.3) beneath the fixed cross-head that carried the mercury piston assembly was drilled out to accept the LVDT body. To avoid the arms springing while this was being done, the yoke was bolted to a jig plate. This also made clamping and alignment of an otherwise strangely formed item easier. The vertical position was not crucial, but the location that provided the greatest mechanical lever for activating the armature was chosen.

The lever arm (part B, Figure 2.3) was then drilled and tapped to match the thread on the armature push rod. A light spring (part F, Figure 2.3) on the armature push rod between the body of the LVDT and the lever arm retained the lever arm in contact with the load-beam pull rod (part E, Figure 2.3) when it was constructed.

The pillar (part C, Figure 2.4) that held the optical transducer for the moving crosshead displacement detector was fastened to the Tensometer base with somewhat enlarged holes to allow for easy alignment. Threading of ~0.9 mm diameter wire through the extra holes in the photocoupler housing provided for this purpose (part D, Figure 2.4) and the perforated disc was the best way to achieve this alignment. After that, alignment may be visually confirmed.

2.4.5 Electrical Design Details

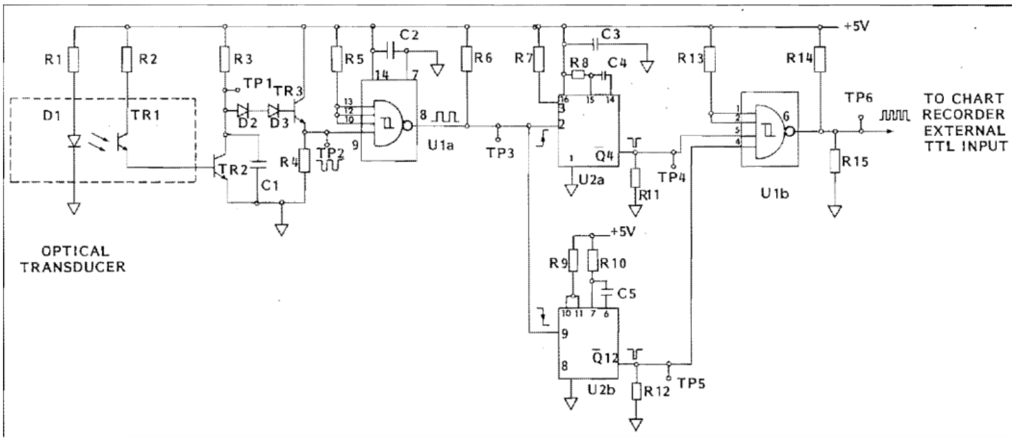


Figure 2.5 Optical transducer and TTL pulse generator circuit

Table 2.1 Component list

Circuit reference	Type/value	Description
U1	7413	Dual 4-input NAND Schmitt Trigger
U2	74123	Dual Monostable Multivibrator
TR1	OP500	Phototransistor
TR2	2N3904	Transistor, NPN
TR3	BC107	Transistor, NPN
D1	OP160	Light Emitting Diode, IR
D2, D3	1N4148	Diode
R1	240 ohm	Resistor, +/- 5%, 1/4W
R2	820 ohm	Resistor, +/- 5%, 1/4W
R3, R6	2.7 kohm	Resistor, +/- 5%, 1/4W
R4	470 ohm	Resistor, +/- 5%, 1/4W
R5, R7, R9, R13	1kohm	Resistor, +/- 5%, 1/4W
R8, R10, R11, R12	10 kohm	Resistor, +/- 5%, 1/4W
R14	2.2 kohm	Resistor, +/- 5%, 1/4W
R15	15 kohm	Resistor, +/- 5%, 1/4W
C1	200 pF	Capacitor, Ceramic, 30V
C2 – C5	0.1 µF	Capacitor, Ceramic, 30V
TP1 – TP6		Test Point

The LVDT employed had a total linear stroke of 2.0 mm and a linearity of 0.1 percent (Sangamo-Schlumberger Type DFg/1.0mm Gold) and was used with matching transducer conditioner (Type DCU1-B) that provided a 5V output with span and zero controls.

The following is a detailed description of how the optical transducer and TTL pulse generator circuit (Figure 2.5) works. The transistor (TR2) switches on when the infrared beam passes from the source (D1) to the detector (TR1), and the voltage at TP1 lowers. When the beam is disrupted, however, the voltage at TP1 rises. Two diodes (D2 and D3) clip the waveform, which is then buffered by the emitter follower (TR3) and moulded by the Schmitt Trigger (U1a).

The monostables and Schmitt Trigger (U1b) that follow modify the pulse width and double the frequency. The rising edge of the entering waveform triggers monostable (U2a), while the falling edge triggers (U2b).

The pulse generator's output (and, indeed, the design of the perforated disc) were matched to the characteristics of the chart recorder to be used (Curken Scientific Inc, single channel recorder, model 125-1), and these elements may need to be modified for different recorders. However, as stated, the circuit generates output pulses with a 4 V amplitude and a pulse width of 0.34 ms at TP6. The disc rotates 300 times per second, producing 300 output pulses. The chart speed selector on the recorder could be used to change the cross-head displacement magnification from x 1/30 to x 60. When the jack connector of the cable from the Tensometer pulse generator was connected, the chart recorder replied to the external TTL pulses, and when the jack plug was removed, the chart recorder responded to its own internal drive.

The recorder utilised has a 5-2-1 stepped attenuator and a maximum calibrated input of 5 V. Working over a 100:1 chart full scale range was possible because to the employment of a single load beam, with electrical noise being a concern below that level. Choosing different load beams, of course, expands the load range accessible [16].

2.4.6 Setting up

All that remains is to match the full-scale output of the transducer conditioner to the chart recorder sensitivity after aligning the mechanical and electrical zeros of the LVDT through adjustment of its location in the yoke and following the manufacturer's recommendations. The transducer conditioner output span is trimmed for calibration with the aid of a dial gauge, taking into account the 1.3 mm deflection of the load beam at full load.

The adjustments presented have been in use for two years of teaching and have proven to be effective in quickly and safely supplying easily understandable data in student projects.

2.5 Bench Top Tensile Testing Machine

2.5.1 Introduction

Figure 2.6 Bench Top Tensile Testing Machine

The Bench Top Tensile Testing Machine is the modern-day type of tensile tester which uses the original concept of Hounsfield Tensometer. The major difference between these two is that there is no autographic drum with graph and mercury used in this machine. It is a small benchtop device that can test metal specimens for simple tensile strength up to a force of 20 kN. An extruded aluminium bed holds the load application and load monitoring equipment in place. By utilising "tie bars," the structure's rigidity is improved.

2.5.2 Load application

A hand-driven worm-and-wheel gearbox drives a lead screw with a travel of around 400 mm in the load application mechanism [19]. Worm gears are spiral-threaded cylindrical gears that are used to drive worm gears in high-speed reduction applications. These gears are often at the correct angle. The worm and the worm wheel are made up of different parts. The worm wheel can be spun, but the worm cannot be turned. Worm gear drives are single-direction drives [17]. A nut on the screw translates along the screw as it revolves. Linear guide rods flowing through the nut prevent the nut from spinning (and so forcing it to translate). A lead screw and a ball screw are nearly identical, except that a ball screw has ball bearings in the nut to reduce screw friction. Rotational motion is converted to linear motion using ball and lead screws. The lead of the screw determines the ratio of linear motion to rotational motion [18]. In the loading direction, the mechanism employs ball races and self-aligning ball thrust races. With the big handwheel and low-friction bearings, the operator can apply maximum weight with minimal effort. They also provide a smooth and progressive action, which is required to assist the operator in applying a consistent strain rate for the optimum outcomes. A smaller "fast advance" hand wheel on the unit allows the operator to rapidly and easily set the distance between the chucks before each test [19].

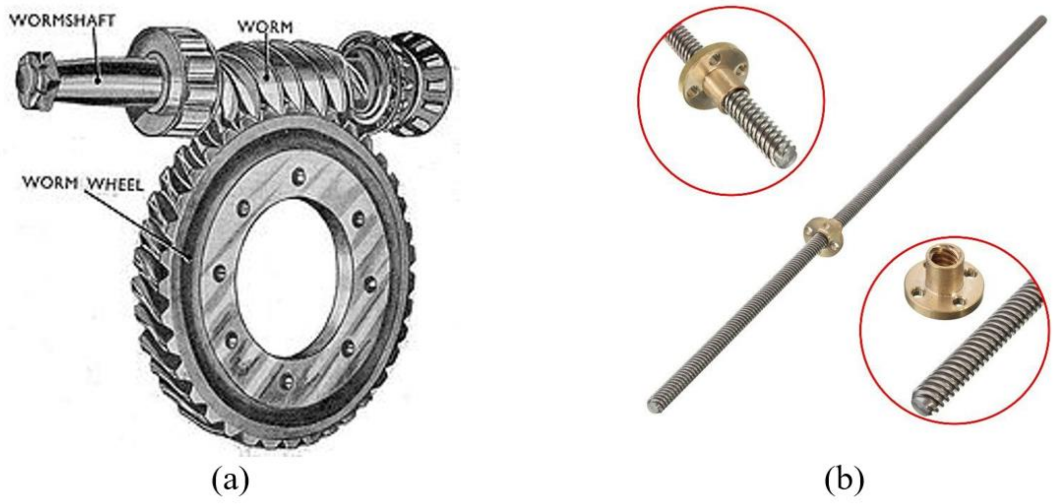
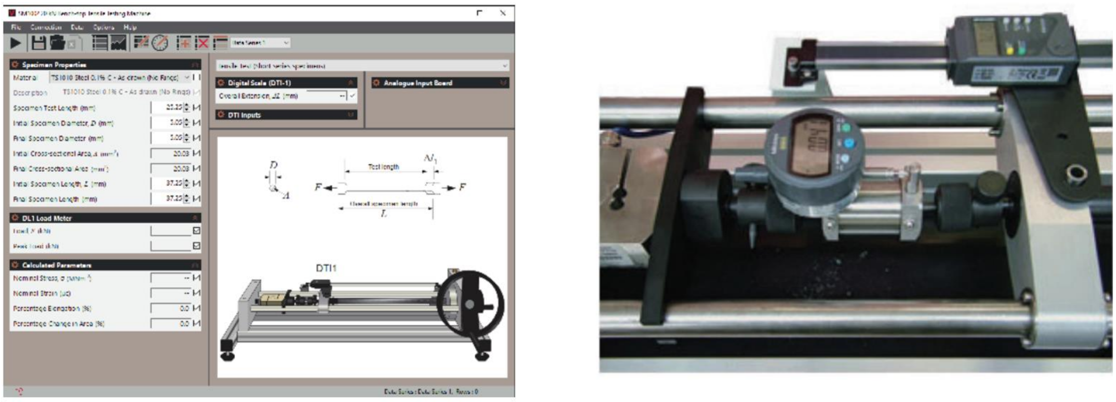


Figure 2.7 Typical image of. a) worm-and-wheel gear and b) lead screw

2.5.3 Load measurement

A strain-gauged load cell links to a microprocessor-controlled digital display as the load measuring mechanism. The 'peak hold' function on the load display unit records the maximum load before the specimen breaks. Over the course of the action, a sliding digital display measures the tensile displacement (extension). For greater strain measurement accuracy and measurements of the material's Young's Modulus, an optional precision extensometer will be available. Any data acquisition system can be used to connect the load, extension, and extensometer displays (DAS) [18].



Material TS1010 Steel 0.1% C - As drawn (No Rings)

Description TS1010 Steel 0.1% C - As drawn (No Rings)

Initial Cross-sectional Area, A (mm²) 20.03

Final Cross-sectional Area (mm²) 20.03

Initial Specimen Length, L (mm) 37.25

Final Specimen Length (mm) 37.25

Overall Extension, ΔL (mm) --

Nominal Stress, σ (MNm⁻²) --

Nominal Strain (με) --

Percentage Elongation (%) 0.0

Percentage Change in Area (%) 0.0

(a)

(b)

Figure 2.8 Load measurement. a) screenshot of VDAS software and b) extensometer

2.5.4 Mounting of specimen

Figure 2.9 Ball-jointed spigot

The tensile specimens are held in collet chucks by ball-jointed spigots (as shown in Figure 2.9) between the load application mechanism and the load cell. This guarantees that the load is exclusively axial. Collet chucks for both long and short specimens with a 20mm^2 area are included with the equipment. With the machine, some companies will include a set of tensile specimens [19]. For example, the company that makes these machines, TecQuipment Ltd, will provide a beginning set of specimens made of two distinct carbon steel alloys (each in their "as drawn" and "annealed" states), brass, and aluminium.

2.5.5 Data acquisition system

The act of sampling signals that measure real-world physical occurrences and transforming them into a digital form that can be controlled by a computer and software is known as data acquisition (abbreviated as DAQ or DAS). The distinction between data acquisition and previous recording technologies such as tape recorders or paper charts is widely recognized. In contrast to other systems, the signals are converted from analogue to digital and then recorded to a digital medium such as ROM, flash media, or hard disc drives. It is very crucial to have a data acquisition system as it will provide users with real time data capture, charting, calculation and exporting of data. The main component in a DAQ is the microcontroller as it governs most operations.

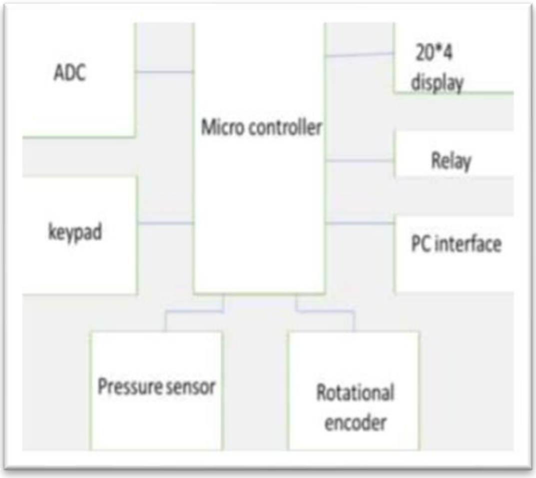


Figure 2.10 Microcontroller block diagram

As an example, let’s look at the AT mega 2560 which is a high performing, low-power microcontroller. The block diagram of this microcontroller is shown in Figure 2.10. There are 54 digital input and output pins on this board. To use the microcontroller, simply plug it into a computer using a USB cable and power it with a battery or an AC-to-DC adapter. The microcontroller's working voltage is 5 volts. There are 16 analogue pins on it. This microcontroller has a variety of specifications such as the following:

a) 86 general purpose I/O lines.

b) High-performance.

c) 6 flexible timer/counters with compare modes.

d) 8KB SRAM.

e) A 16-channel 10-bit A/D converter.

f) PWM.

g) 32 general purpose working registers.

h) Real time counter.

i) ISP flash memory.

j) Oriented 2-wire serial interface.

This microchip-based microcontroller runs between 4.5 and 5.5 volts and has a throughput of 16 MIPS at 16 MHz. The device derives a throughput approaching 1 MIPS per MHz, processing speed, and balancing consumption of power from a single clock cycle executed by strong instructions.

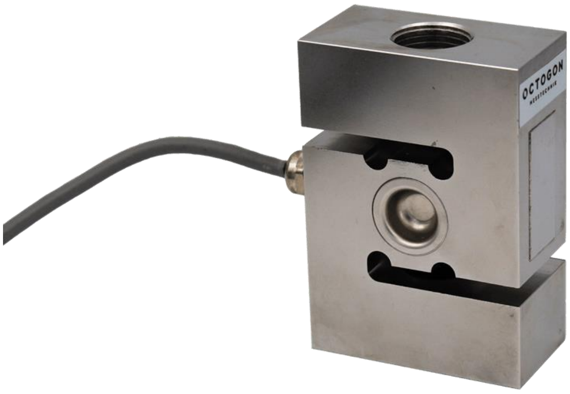


Figure 2.11 Typical load cell

The second crucial hardware is the load cell. A load cell (as shown in Figure 2.11) is a device that converts force into electrical output that can be measured. Despite the fact that there are many different types of load cells, strain gauge load cells are the most prevalent. Strain gauge load cells dominate the weighing industry in laboratories that still employ precision mechanical balances. Pneumatic load cells are occasionally utilized in distant places where intrinsic safety and cleanliness are desired, while hydraulic load cells are explored since they do not require a power supply. Strain gauge load cells are suited for practically all industrial applications, with accuracies ranging from 0.03 percent to 0.25 percent full scale. The strain gauge (a planer resistor) deforms when the materials on the load cells deform suitably, which is how strain gauge load cells operate. A load cell in a Wheatstone bridge is normally made up of four strain gauges. The load cell's output voltage is 2mv/v.

CHAPTER 3

METHODOLOGY

3.1 Worm wheel Reduction Gearbox

3.1.1 Introduction

At the beginning of the project, there was an initial proposed solution to this problem. The load application method of the previously mentioned Bench Top Testing Machine [19] which is the worm-and-wheel gearbox drive was to be employed with the combination of rack and pinion gear. There are certain things to be reviewed throughout this project. First of all, the low strain rate tensile machine should be fabricated in a way that it is a part of a large hybrid machine. This is done by using the transmission bar of the Split Hopkinson Pressure Bar device which acts as the fixed end that holds the specimen. Whenever a low strain rate test is to be carried out, the rear end of the SHPB which has the transmission bar will be used. Other than that, the reduction ratio of the gearbox being used to pull the specimen must be 50:1 and this can be done using worm and worm wheel gear type. The ratio 50:1 means that 50 rotation of the worm gear gives one complete revolution of the worm wheel and this is because the rate of strain experienced by the specimen should be very low. The rotating worm wheel will then convert its rotational motion into linear motion using a rack which is connected to the other pulling end of the device. Besides that, when the rack gear is being linearly moved by the worm wheel, it will be sliding inside the space of the housing. This movement will create friction between the rack gear and the housing. To avoid this, some rollers should be added in that space so that the rack gear will slide between them smoothly thus reducing friction. The reduction gearbox is the most important part for the low strain rate feature. The proposed solution for the design of the worm wheel and gear will be shown below. This project can be tackled by following a series of subsequent processes that are very crucial in designing the low strain rate feature.

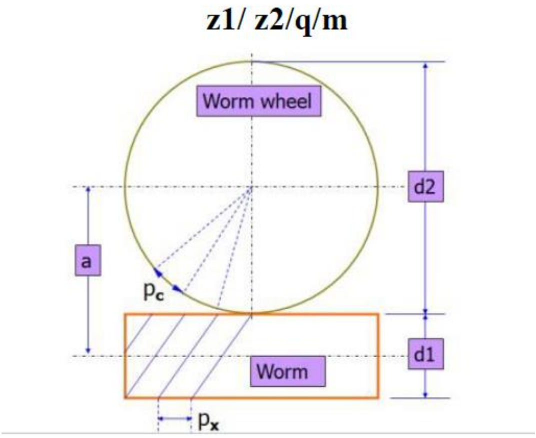


Figure 3.1 Terminology of Worm and Worm Wheel

Figure 3.1 shows the typical appearance of a worm and worm gear that will be used in the reduction gearbox while figure 2 shows the terminology for the worm drive.

Where,

z_1 = no. of start on worm

z_2 = no. of teeth on worm wheel

q = diametral quotient = d1/m

m = module

Axial Pitch - **(p_x)** defined as distance between two consecutive teeth measured along the axis of worm.

Lead **(l) –** It is defined as distance that a point on helical profile will move in axial direction when worm is rotated through one revolution.

$$l = px * z1 \tag{1}$$

Circular Pitch - **(p_c)** distance measured along pitch circle from one point on one tooth to the corresponding point on the adjacent tooth.

Lead angle of worm **(γ) -** When one thread of worm is developed it becomes hypotenuse of the triangle. Thebase of triangle is equal to circumference of worm & altitude is equal to lead of worm.

$$tan\gamma = \frac{z_1}{q} \qquad 2$$

3.1.2 Initial design of Worm Gear set

An initial worm gear set was designed to be used in the reducer that functions to apply tension onto the specimen being tested. These worm and worm gear were designed using dimension approximate dimension without any prior calculation just to have an idea on how it would come together. Figure 3.2 shows the drawing of worm and worm gear while Figure 3.3 shows the whole gearbox design.

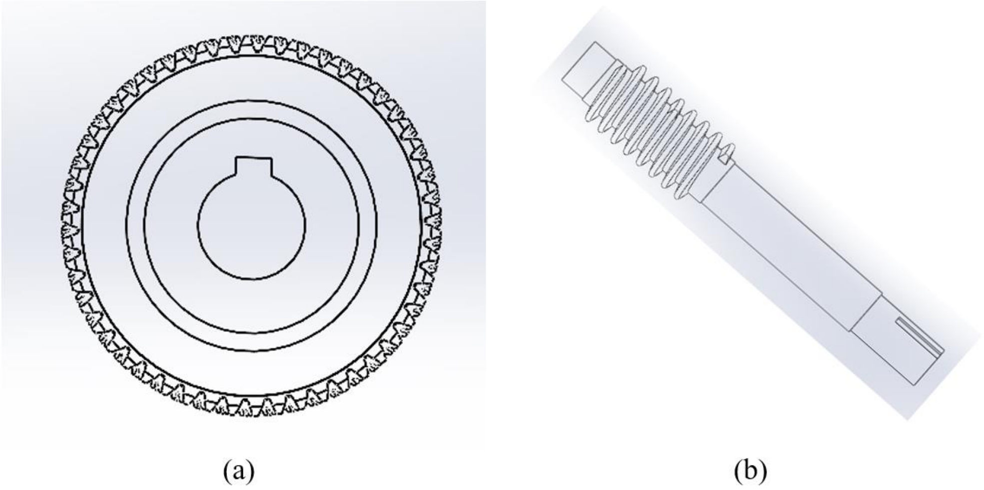

(a) (b)

Figure 3.2 Drawing of a) Worm wheel and b) Worm gear

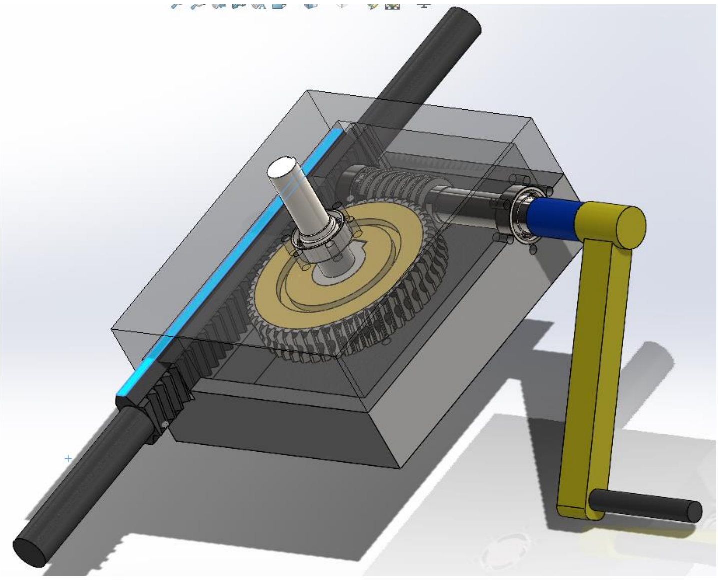


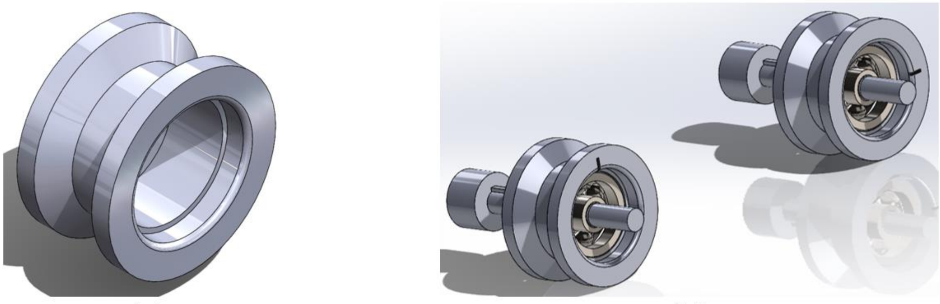
Figure 3.3	Solidworks drawing of whole gearbox

The worm and wheel reduction gears will then transmit the force onto a rack gear. The rack gear will slide inside housing according to the rotation of the wheel. The rack gear will slide with the help of rollers and bearings. The sliding part of the gearbox is currently under progress. The figure shown below is the first and initial design of the gearbox subject for amendments. As the handle is rotated manually, the worm rotates with it as well following the speed of the handle movement. The worm which is meshed with the wheel will cause the wheel to rotate with it with a gear ratio of 50:1. This ratio simply means 50 rotations of the handle will produce 1 complete revolution of the wheel. The wheel as mentioned above will transmit the force onto a rack gear which sits in a housing. That rack gear will be connected to the pulling end of the low strain rate tensile tester which will move backwards at a slow and constant speed applying steady tension to the specimen being tested.

3.1.3 Initial design of rack gear hosuing

As for the design of the rack gear slider, it was being modified and updated. In the initial design of the gearbox shown, the rack gear slides within the space in housing with maximum contact on the surface. This will cause higher friction and heat which leads to permanent damage to the housing and rack gear. This damage can be avoided by lowering the amount of friction acting on both the gear and housing. This could be done by decreasing the area of contact between the two surfaces.

One of the simplest ways that can be done to achieve low friction is by adding rollers. These rollers that are present in the sliding space of the housing could make the rack gear to slide with lesser friction. Not only it reduces the friction, the rollers also is designed in such a shape so that it could hold the moving rack gear in one gear for smooth and neat sliding movement. For this purpose, the material for the rollers will be Teflon. The strong and efficient teflon roller are made of sturdy materials such as metal and alloys that are intended towards enhancing the durability of the sliding mechanism and offer optimal sustainability. These rollers are eco-friendly and are cost-effective options for this type of industrial purpose Regardless of how extensively they are used or under what conditions they are being used, these teflon roller can resist all the impacts and perform flawlessly. These teflon roller are equipped with unique features and are available in customized variations and sizes. Figure 3.4 shows the design of the roller and the rollers with bearings and shafts.



(a) (b)

Figure 3.4 Design of a) Roller and b) Rollers with bearing and shafts