Design and Fabrication of an Industrial Thread Tension-testing Machine which provides a Quality-testing Solution to manufacturer of Suturing Needle Holder

By

Muhammad Kashan Siddiqui

00000148449 (Fall 2015 – BME)

School of Mechanical and Manufacturing Engineering

National University of Sciences and Technology

H-12 Islamabad, Pakistan

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Muhammad Kashan Siddiqui

00000148449 (Fall 2015 – BME)

Supervised by: **Dr Murtaza Najabat Ali**

School of Mechanical and Manufacturing Engineering

National University of Sciences and Technology

H-12 Islamabad, Pakistan

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Certified that final copy of MS Thesis written by *Mr Muhammad Kashan Siddiqui*, *(Registration No. 00000148449)*, of *School of Mechanical and Manufacturing Engineering (SMME – NUST)* has been vetted by undersigned, found complete in all respects as per NUST Statutes /Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS/MPhil Degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

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2. Name: _Dr Adeeb Shahzad Signature:_______________

3. Name: _Mr Usman Daud Sair Signature:_______________

Supervisor's name: Dr Murtaza Najabat Ali Signature:_______________

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DECLARATION

It is hereby declared that this research study has been done in partial fulfilment of requirements for the degree of Masters of Sciences in Biomedical Engineering. This work has not been taken from any publication. I hereby also declare that no portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification in this university or other institutes of learning.

Muhammad Kashan Siddiqui

DEDICATION

I dedicate this thesis to my teachers' guidance that never stopped pouring in; and to the inspiration I seek, which I pray may never see an end.

PATENT

1. Murtaza Najabat Ali, Muhammad Kashan Siddiqui, "Industrial Automation Solution for Quality-testing of Suturing Needle Holder". Patent application filed with Intellectual Property Organization (IPO) of Pakistan through NUST IP Office on 8 Aug 2017. (scanned copies of patent application Form P-1 and Form P-28 are attached in Appendix A)

ACKNOWLEDGEMENTS

I humbly bow in gratitude to Allah Almighty for every blessing of my life.

I would like to thank my thesis advisor Dr Murtaza Najabat Ali for selecting and putting his trust in me in this project-based thesis involving real-life designing, fabrication and commissioning. The door to his office was always open whenever I ran into a trouble spot or had a question about my project or writing. He consistently allowed this paper to be my own work, but steered me in the right direction whenever he thought I needed it.

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I would also like to thank the experts who were involved in the validation of design and its manufacturing stages: Dr Umar Ansari (BMES-SMME), Mr Haris Ali (MDDC-NUST), Engineers Mr Abdul Hadi and Mr Huzaifa (Kounter Intuitive Technologies), Workshop Supervisor Mr Afzal Mughal. Without their willful participation and input, the immense fabrication process could not have been successfully implemented.

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Muhammad Kashan Siddiqui

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LIST OF ABBREVIATIONS

Millimeter	mm	Volts	V
Stainless Steel	SS	Watts	W
Mild Steel	MS	Revolutions per Minute	rpm
Aluminum	Al	Diameter	dia
Grams	g	SolidWorks	SW
Milligrams	mg	Degrees	deg
Alternating Current	AC		
Direct Current	DC		

LIST OF ILLUSTRATIONS

ABSTRACT

Biomedical devices are manufactured just like other products except for they are required to undergo strict quality tests to qualify stringent standards. Sialkot is manufacturing hub of biomedical devices, where most of the products are designed for both domestic and international markets. Dr Frigz International (Pvt) Ltd manufactures a brand of Needle Holders used in operation theatres for manual suturing.

The device is manufactured through conventional processes and machining techniques. But through last few stages, the dimensional accuracy and functional quality is given great consideration. One such test is the ability of the Needle Holder to effectively hold suturing thread when given tension. This specific test is conventionally performed by hand, and therefore lot to lot inconsistencies are imminent.

The aim of this project-based thesis is to design and fabricate an automation system which would not only speed up the quality-testing process but also ensure consistent test parameters for pass/fail labelling of Needle Holders.

Key words: *Suturing, Needle Holder, Industrial Automation, Quality testing, System design.*

CHAPTER 1 – INTRODUCTION

A needle holder is used by surgeons to hold and manoeuver surgical needle and the thread (suture) during suturing. A needle holder is shown in Figure 1. The surgeon grips the needle in between the jaws of holder and presses on to the ratchet for at least three clicks. The suturing process occurs mostly towards the end of the surgical procedure and it is imperative that it goes on in a very smooth manner, i.e., without causing any discomfort and / or inconvenience to the surgeon or assisting staff. During the holding phase, needle or thread must not slip through the jaws of needle holder. Also, sharp edges of needle holder must not cut through the suturing thread.

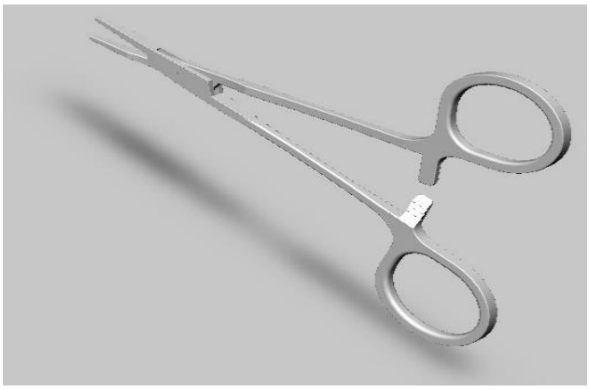

Figure 1: A Needle Holder

The Needle Holder quality testing procedures necessitate a tension test and a sharpness test; in a conventional tension test, a piece of suture is held tightly in the Needle Holder and pulled by hand whereas in a sharpness test, similar procedure is repeated only this time the Needle Holder is tilted by 30 degrees on either side to check for sharp edges.

Dr Frigz International (Pvt) Ltd, a biomedical and surgical instruments manufacturer based in Sialkot, approached SMME – NUST through Kounter Intuitive Technologies for an engineering solution their product (Needle Holder) testing procedure. The dilemma caused by the manual non-automated testing procedure is two-folds; one, it cannot assure the manufacturer whether the PASSED piece was actually pass or FAILED piece was actually fail, and secondly, lot to lot variations in thread tension tests decrease the reliability of process. Therefore, the manufacturer wished for a rig (or a machine) which would automate the process through computer-numeric control and sensing.

CHAPTER 2 – REVIEW OF LITERATURE

2.1 Background of Project

A needle holder, also called needle driver, is a surgical instrument, similar to a hemostat, used by doctors and surgeons to hold a suturing needle for closing wounds during suturing and surgical procedures. The parts of a simple needle holder are the jaws, the joint and the handles. Most needle holders also have a clamp mechanism that locks the needle in place, allowing the user to maneuver the needle through various tissues. To maintain a firm grip on the needle, the jaws are often textured and short compared to the handles (increasing the applied force following the principle of a lever). [1]

The Needle Holder quality testing procedures necessitate a tension test and a sharpness test; in a conventional tension test, a piece of suture is held tightly in the Needle Holder and pulled by hand whereas in a sharpness test, similar procedure is repeated only this time the Needle Holder is tilted by 30 degrees on either side to check for sharp edges.

A biomedical and surgical instruments manufacturer, Dr Frigz International (Pvt) Ltd Sialkot, approached for an engineering solution to one of their product (Needle Holder) testing procedure. The dilemma caused by the manual non-automated testing procedure is two-folds; one, it cannot assure the manufacturer whether the PASSED piece was actually pass or FAILED piece was actually fail, and secondly, lot to lot variations in thread tension tests decrease the reliability of process. They had an issue with quality complaints whereby a noticeable percentage of finished pieces got returned a number of time to re-working stations. There were also instance when some pieces which were passed by quality testing department, got observed by the client in USA as failed pieces and were returned. It became a question of customer's trust and manufacturer's confidence in the product's quality testing protocols.

2.2 Search of Key Words

Based upon the processes mentioned above, following various keywords were searched (using various combinations) through databases of scholarly articles and patents. There is a definite lack of literature on specific keywords such as Needle holder, Needle driver, Tension test, Thread loading, Thread tension etc. The search results did not show any relevant reference material. Most of the mechanisms and automation processes were related to looms and / or sewing machine threads, which have different utility of the loaded thread.

This lack of literature on the precise subject was deemed to support the argument tendered by Sialkot manufacturer, i.e., the process has not been automated yet and that it is being practiced by hand or manually around the world. Gebrüder Martin GmbH & Co. of KLS Martin Group was quoted as an example. Conversely, this might also be an indication that there exists such technology for quality testing of needle holders but has been protected and guarded as trade secret. Therefore, various related searches consolidated into the current design of this machine.

2.3 Needle Holder Test Parameters

Haddad D, Worst suggests that a needle holder should be able to hold a hair on the back of your hand. If not, it is not functioning properly. [2] Due to hand-worked and adjusted pieces, it is possible that the mating surfaces do not meet well and there remains a space in between. This has a direct effect on the grip of needle holder on to the needle and / or suture.

Figure 2: A Defective Needle Holder

Schultz suggests a method of checking the bent jaw. When the needle holder is held up against a bright light in back ground while its jaws are pressed closed, no light should be visible through the jaw mating surfaces. If the jaw is worn, the workpiece is returned by quality assurance department for re-working. [3]

2.4 Requirement of High Precision Functioning by Surgeons

It is imperative that the needle holder is of high dimensional and functional accuracy. The surgeons' concentration should remain on the operative procedure and not on whether the needle holder is gripping the needle or thread properly. There are various delicate manoeuvers in surgical operative procedures, The tissue anchor, The Tak manoeuvre, The Saatvedt swing, The Large flip, The pirouette etc. [4] The surgical manoeuvers are challenging and may be hampered with needle holders slipping the needle or thread.

2.5 Existing Grip Testing Procedures

Clamping jaws of a needle holder have to close flush when the ratchet is pressed close. Only then can it be assured that the holder will not slip the needle or suture during surgical operating procedures. The customary method of checking this is visual assessment in that closed jaws of needle holder are place in front of a bright light source, and it is checked if there is a visible light peeping in between the mating surfaces. If light can be seen, it means there is a gap and will slip the needle or the thread. [5]

2.6 Loading of Thread under Tension

The first step in automating the needle holder gripping test is to be able to hold a thread under slight taut tension such that it does not move or change positional track during gripping by the needle holder. The basic idea was to hold the thread in between two curved plates which are being pressed against each other by a spring. This very idea came from a sewing machine which is a marvelous manipulator of thread under tension. [6]

Figure 3: Thread Tension Adjuster in Sewing Machine

One curved plate is static or press-fit to the base of the post whereas the second curved plate is free. There is a central pin going from the base outward which carries the free second curved plate. A spring is mounted over the second curved plate and secured in place by a round nut. Tightening the nut increases the gripping force between the plates and loosening the nut decreases the gripping force.

2.7 Measuring Thread Tension

Leonard Samuel Lindley in his patent suggested that a force sensor disk, a tension spring washer, a tension spring and a tension adjusting knob could be used to measure the tension of a running thread in real time. [6] The data could be used to increase or decrease the thread tension in the sewing machine for better stitch quality. [7]

The idea has been followed in a sense that a sensitive load cell is used to measure the force being experienced by the loading arm due to the pulling force on the thread. A Double bending beam load cell element type has been used in this machine. [8]

Load cell outputs voltage data based upon the principle of strain gauge. It varies voltage according to the applied force. The real-time voltage data is fed into ADC of a microcontroller which then converts the ADC data into weight values. [9]

Figure 4: A Double Bending Beam Load Cell

CHAPTER 3 – MATERIALS AND METHODS

3.1 Needle Holder

3.1.1 Manufacturing Process

The manufacturing process of Needle Holder follows various steps. Forged singles of the holder are received in factory from vendors. The material is malleable and can be worked by hand. It is filed using hand tools and machines to carve into male and female parts. After the holder is assembled, the process of finishing commences. The surface is treated with chemical passivation and smooth grinding and lapping. After the insertion of pin and adjustment of its smooth operation, the needle holder is brought to final stage where fine adjustment and polishing takes place.

At this stage of manufacturing, quality testing and finer adjustments are made. Skilled labor sits on table and carefully inspect each piece against background of a bright light. Any visible crevices are hand-tapped lightly so that the jaws of needle holder close properly and flush together well. This process take place in batches of needle holder and numerous workers undertake this task.

3.1.2 Manual Quality Testing Procedure

In the final stage of quality testing, actual suturing thread made of organic silk is used to verify the contact surfaces of holder. The silk thread is very expensive and is provided by the main client of this factory. In this stage of quality testing, mostly females are employed as skilled workers keeping in mind the delicacy of the process.

Figure 5: Needle Holder Thread Tension Testing by hand

In manual quality testing procedure, as shown in Figure 2, a small piece of hanging silk thread is pressed in between the jaws of needle holder and ratchet is locked into third notch. Then the thread is pulled and tension it causes is judged by the skilled worker. This process is repeated at three points of needle holder mating surfaces: at the tip, in the middle, and at the rearmost position of jaws, as shown in Figure 3. In this process, if the thread slips between the gripping jaws it means that the surfaces are not flush enough and the piece is rejected. Rejected pieces are returned the re-working stations where they are hand worked again to adjust the faulty mating surfaces.

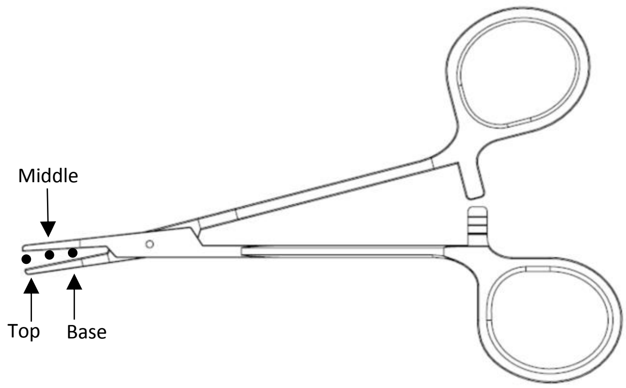

Figure 6: Three points of tension testing

In addition to slippage test of thread, cutting test is also performed to check if any edge of needle holder has remained with burrs. To perform this test, the skilled worker grabs a piece of silk suture thread in between the jaws of needle holder and pulls lightly, only this time the needle holder is held at an angle of roughly 30 degrees such that the thread would break if there are any rough edges left after the finishing processes. Rejected pieces are returned the re-working stations where they are hand grinded again to adjust the faulty sharp surfaces.

3.2 Automation Plan

The task at hand was to introduce an automated industrial solution to the quality testing procedure of Needle Holder. The industry asked the team of experts to visit the factory and assess the possibility of designing an automatic machine which has the capability of carrying out quality testing procedure with reliability and speed.

3.2.1 Automation Assessment

While it appears to be a very simple sequence of actions performed manually by expert hands of skilled workers, the proposed automation process warrants combining very delicate and complicated thread manipulation feats. The process would necessitate following processes to be run in sequence (or some in parallel):-

- Loading of thread in space between two posts under pre-tension.
- Holding of Needle Holder in a clamp and feeding it onto the thread.
- Closing the grip of Needle Holder such that it is stout in test position.
- Pulling thread and Needle Holder apart and recording the amount of tension exerted before the thread slips or break.
- Performing this tension test at three locations between Needle Holder jaws (4mm apart) which necessitates new loading of thread for every test instance.
- Performing sharpness test by rotating the Needle Holder 30 degrees (either sides) and pulling thread to check for sharp edges.
- After test, disposing the Needle Holder with check flags of 5 possible test results.
- Loading of next Needle Holder onto the Holder Post while test is being performed on previous piece.

The design of these processes had to cover various fields of study instead of just one. Knowledge and application of Engineering Mechanics, Design of Machinery and Machine Elements, Medical Devices Design and Standards, Mechanics of Materials, Conventional Manufacturing Processes, Industrial Automation and Controls Systems, was imperative.

3.2.2 Building Blocks of Automation Solution

A complete illustration of the machine is given in Figure 4 below. First main task was to design a rig which was capable of holding the testing thread in tension so that a needle holder could grip it. This part of the machine was named as “Thread Post” or “T-post”(11). It was proposed that there be kept at least three T-posts to serially test needle holders for three positions of gripping, i.e., tip, middle, and base.

After the setting of T-post, another post was required to be designed which was capable of holding and feeding needle holder into three positions on to the testing thread. The post was termed as “Holder Post”, or simply “H-post”(9). Since the needle holder had to be manipulated in three steps, H-post was required to perform following functions:-

- Extend the needle holder into three positions on to the thread and retract afterwards.
- Close the jaws of needle holder such that the thread is gripped in between the mating surfaces and open the jaws afterwards.
- Rotate the needle holder such that test for sharpness of edges could be performed.

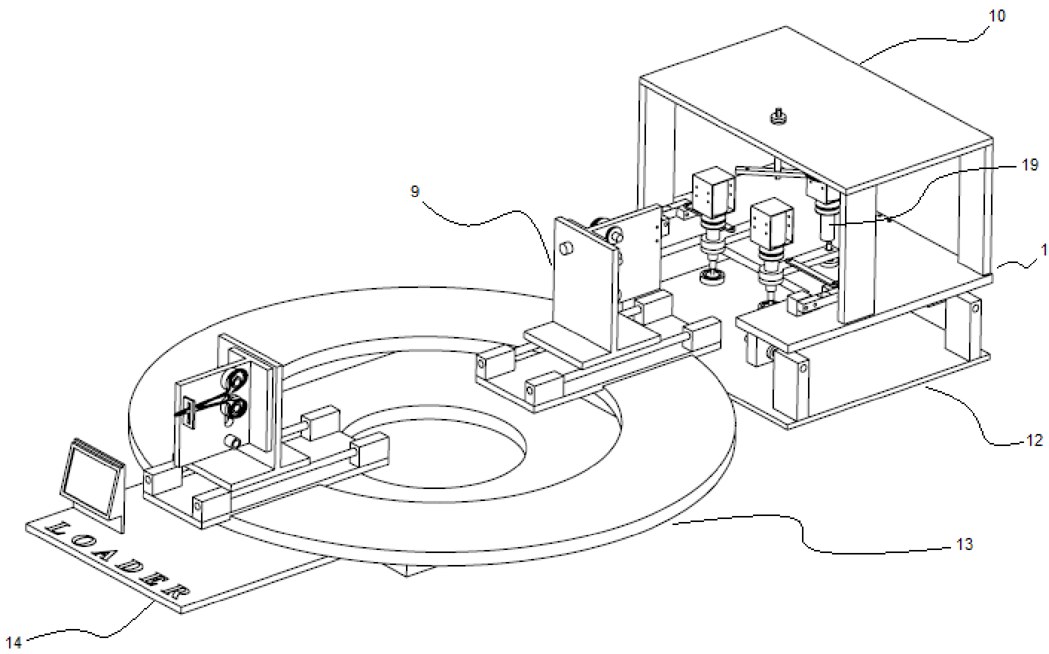

Figure 7: Complete machine

3.2.3 Automation Scheme

The main design of automation solution was kept modular. The machine was initially named as “Needle Holder Thread Tension Testing Machine”; later the name was affectionately short-formed to be called as “Tension Testing Machine”. It had to be a fully automatic process with zero or minimal operator intervention. But it was decided that the design and fabrication process will start with smaller modules and the machine will develop by integrating these modules into each other.

Main schematic of the mechanism was planned to be based upon conveyor-loading and unloading, as shown in Figure 4. Three T-posts were planned to address the tension testing of three positions of the needle holder, i.e., tip, middle and base. H-posts were planned to operate in the sense of a conveyor system in which an operator (or automatic loading carousel/cassette) will load the test pieces in a serial manner and unload the tested and flagged pieces into respective bins located at pre-programmed positions.

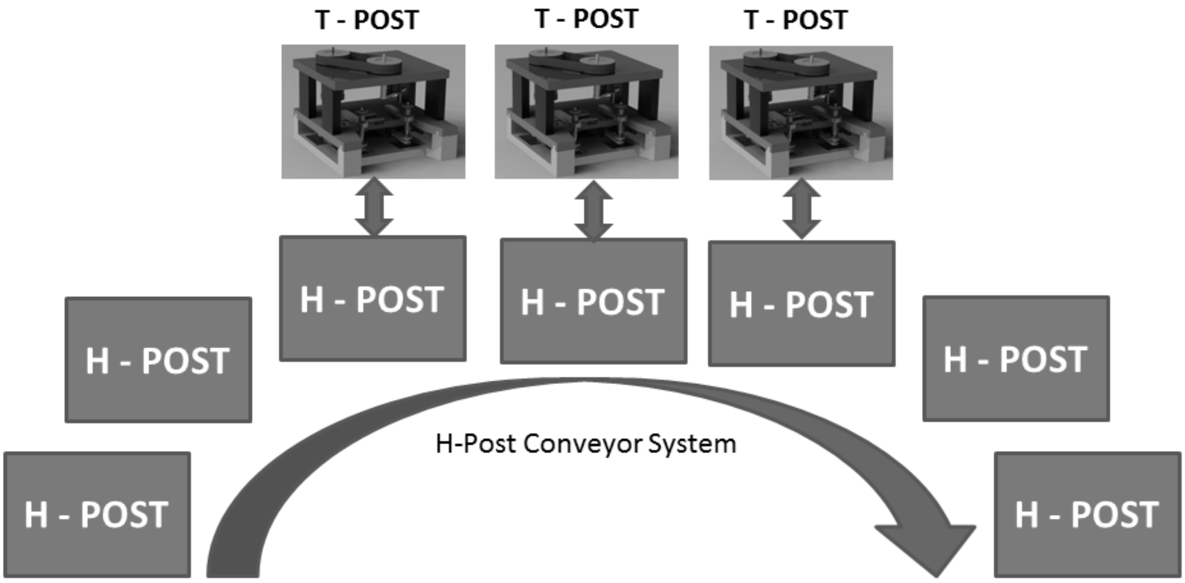

Figure 8: Proposed Automation Scheme

3.2.4 Control System

The automation system was planned to be controlled using microcontroller, sensors and actuators. The industrial application of the machine warranted some definite requirements from the electro-mechanical control system as follows:-

- Accuracy of test parameters
- Speed of execution and process optimization
- Flexibility of design to incorporate expansion
- Acceptability of various sizes of work pieces
- Integration of electronics and mechanical components
- Economic feasibility of the project
- Robust design to withstand long term deployment
- Minimum requirement of preventive maintenance
- Emphasis on quality manufacturing of parts and assemblies

- Thread Characterization

Before the fabrication of actual machine parts, the braided silk suturing thread was examined. It was tested for its breaking strength under impulse loading conditions as well as gradual loading conditions. The tests were carried out using common lab equipment available in Prosthetics and Implantology Lab of SMME. It was concluded in the experiment that the thread breaks under gradual loading of weight equal to 350g. Under impulse loading, it broke with a weight of 250.

3.3 Fabrication of Machine

The machine was to be fabricated using commercially available material including mild steel, stainless steel, aluminum, acrylic and Teflon. It was planned in a manner such that the designing process preceded the manufacturing process of the components by a few steps only. In this way, an unexpected design failure would not cause numerous fabricated parts to go useless. Parts and assembly drawings have been included in this booklet as Appendix C.

3.3.1 Thread Post (T-post)

A custom design thread gripper post holds the thread in between two curved plates under the tension of a spring. See figure 5 below. The lower curved plate (2) is press-fit onto the barrel (3) of the assembly. The upper curved plate (1) is mounted on the central rod (7) through washer and nut arrangement. The spring holds the thread in tension through a central rod that runs from the bottom adjuster plate (8) of spring up to the top plate. The adjuster plate screws itself into the central rod, thus rotating it increases or decreases the force with which two curved plates are pressed against each other. This also, in turn, adjusts the amount of force with which thread is held by the thread gripper. The barrel of thread gripper is press fit on to the plate (4) which can carry the load of all these parts. The thread gripper plate pivots through a pivot pin (5) at its fixed end. The pivot pin is a shaft which assembles

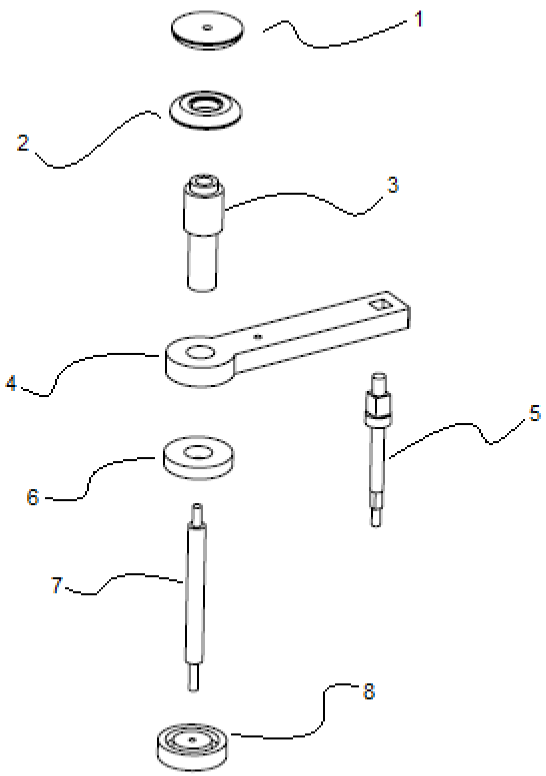

Figure 9: Parts of Thread Gripper Post

through the plate at its one end with square keyed insertion, and passes through a brass bush press-fit into the moving platform. The entire thread gripper is able to rotate freely on the pivot pin with least amount of friction caused by contact surfaces of steel (pin) and brass (bush). A locking washer and nut combination stops the pivot shaft to come off the bush, i.e., its axial movement is restricted.

A high power solenoid (15) is mounted on top of the upper curved plate (1). When energized, the solenoid (operating on 220 V) pulls the central rod (7) along with upper curved plate (1) in a way that the thread pressed in between the two plates becomes free to be pulled out. The duration of energization had to be kept minimal because the solenoid may get heated up on continuous operation. When the solenoid is de-energized, it releases the central rod (7) and upper curved plate (1) thus causing the two curved plates to hold the thread tightly again. It must be borne in mind that the silk thread once pressed in between the two curved plates gets crimped and its strength at the crimped location decreases.

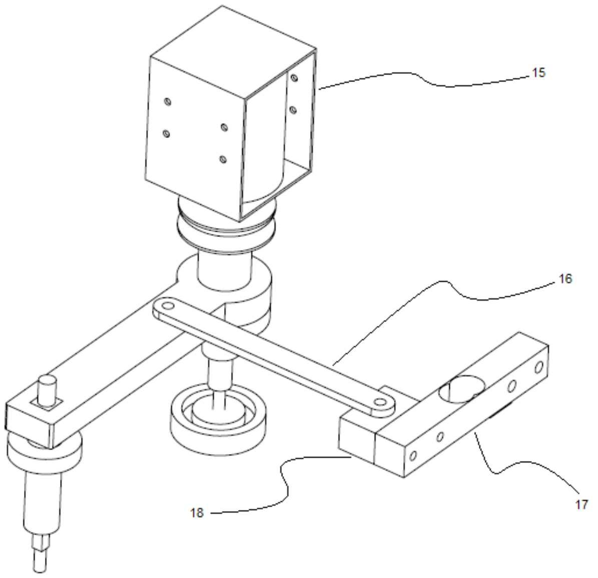

Figure 10: Thread Gripper Post with Solenoid and Load Cell

A holding block fastens the load cell (17) to the base of moving platform (11). A commercially available high sensitivity 2kg digital weight sensor A-1073 is used which can sense changing load conditions based upon the principle of strain gauges. A connecting link (16) installs between the free end of the load cell (17) and the moving plate (4) of thread post. Both ends of the link are kept as pin joints to ensure detection of smallest of the forces exerted by pulling of thread through deflection of the plate (4).

The thread gripper, solenoid, pivot shaft and load cell is replicated to hold the testing thread on both sides of the moving platform. In this way, thread tension can be measured independently by pulling in both right and left directions. There is a third static gripper post (19) fixed into moving platform (11) towards the back. Its function is to grip the thread for the first time and then onwards in the beginning of every test step. This third gripper post does not move on pivot and it also does not have a load cell attached to it.

3.3.2 Moving Platform

The moving platform (11) is mounted through rail-blocks (20) on to the fixed platform (12). Two stainless steel guide rods (25) run along the breadth of the fixed platform (12), anchored by aluminum blocks (20). Four blocks with linear bearings (26) hold the moving platform on the sliding guide rods (25) of fixed platform (12), two on each rod. The linear bearings (26) ensure that the moving platform moves relative to fixed platform with minimal friction. In addition, guide rods (25) are lubricated with machine-grade grease. Guide rods are installed on the front and back of fixed platform (12) to allow for sideways motion of moving platform (11).

A 12V DC motor (21) is installed on the fixed platform (12). The motor has an extended shaft over which an eccentric bush (22) is mounted. The eccentricity of the bush is calculated and affixed to 5mm. A plate (23) with vertical guide slot (24) is installed at the bottom of the moving platform (11) at a position such that the extended lug of the eccentric bush (22) runs inside the guide slot (24). When the moving platform (11) is assembled on to guide rods (25) and DC motor (21) is energized, the eccentric bush (22) causes moving platform (11) to sway right and left. This motion of moving platform (11) occurs once for every one rotation of the DC motor (21).

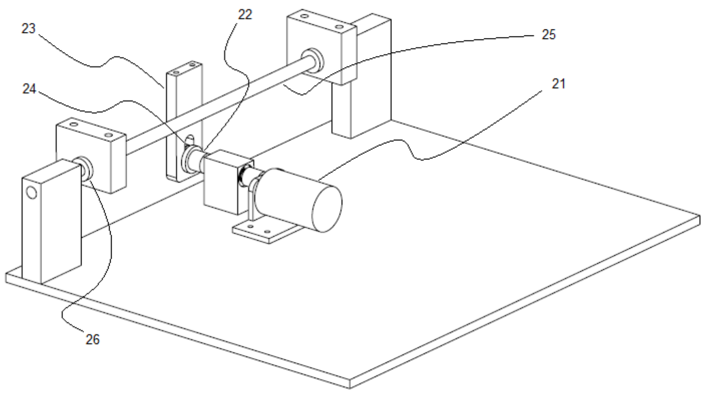

Figure 11: 12V DC Motor and Fixed Platform

There is a loading arm (27) mounted under the top plate (10). It is a long piece of aluminum strip which has a pin (32) for holding silk thread reel (33). The thread from reel unwinds along the loading arm (27), over the long hanging end and through the metallic hook (34). The hook (34) is placed at a height equal to the where two curved plates (1 & 2) meet. The loading arm (27) pivots through a central shaft (29) onto bush (30) mounted in top plate (10). The shaft extends beyond the top plate and a metallic coupling joins the shaft of loader arm (31) to that of a stepper motor. The stepper motor is a 12V motor with 1.8 degree rotation per step. It is capable of rotating the loader arm (27) through 360 degrees, with pre-programmed stop positions. The smaller free end (28) of loader arm (27) is there to counter the off-center mass of rotating loader arm.

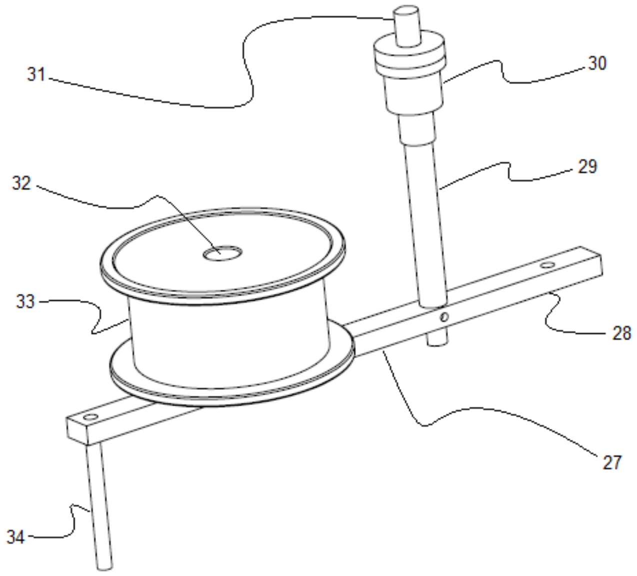

Figure 12: Thread Loading Arm

3.3.3 Holder Post (H-post)

There are synchronous as well as sequential steps which are carried out by H-post (9). The needle holder (35) is loaded with its handles inserted onto two lugs (36 & 37) meant to grip it. One of the lugs (36) is stationary, while the other one (37) moves through a 12V stepper motor and actuator mechanism to open and close the jaws of needle holder (35). The lugs (36 & 37) are curve-shaped to prevent the needle holder (35) from tipping over while it is being pressed close by the lugs (36 & 37). There is a slot (38) towards the front of H-post (9) through which the needle

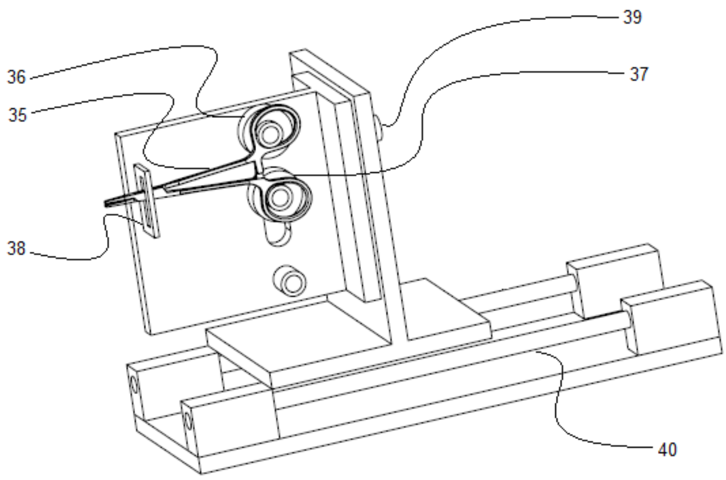

Figure 13: H-Post

holder (35) is passed while loading. This slot (38) keeps the needle holder (35) from moving right or left when being pressed closed by lugs (36 & 37).

The jaw closing mechanism of the H-post including the lugs and motor, can swivel on a pin joint (39) which is there to rotate the needle holder (35) up to 30 degrees. This is done to test the needle holder for sharpness of edges and burrs. This rotation is carried out by stepper motor and actuator mechanism and is controlled through microcontroller.

Jaw closing mechanism along with swivel mechanism is in turn able to move forward and backwards on parallel guide rails (40). These rails are made up of 8mm stainless steel rods on which the entire assembly is mounted through linear bearings. These linear bearings are used to minimize the effects of friction thereby reducing load on the drive mechanism. Forward and backwards movement is carried out using 12V DC motor and rack-pinion gear arrangement. Since most of the load is taken up by guide rails, Teflon gears are preferred to be used in drive mechanism. Position of forward and backwards extremes are controlled by use of IR position sensor which is able to measure and output the real-time distance of post from forward extreme position.

It was initially proposed that there would be a total of six H-posts mounted serially onto conveyor system, for automatic loading and unloading of test pieces. However, due to limitation of time it was decided that the prototype machine would have two H-posts operating on a ring loader where operator will be able to load and unload test pieces at one position. The ring takes drive through a large gear driven by a pinion gear through a 12V DC motor. Two Position switches are placed underneath the ring loader to stop the drive at preset positions.

3.3.4 Electronics and Controls

Entire control system is based upon Arduino Mega 2560, a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila. Arduino programming code (commonly known as Sketch) has been given in Appendix D. One controller each is dedicated to drive the T-post and the H-post. A schematic diagram of electronics and controls is given in Figure 5 below.

Solenoids mounted on the thread gripper posts are driven by 220V. This is accomplished by using off the shelf 4-Channel Relay Module compatible with AVR microcontrollers (such as Arduino Mega). In this way, a 5V TTL signal from Arduino to relay module energizes the solenoid and it remains as such until the 5V signal is present. 12V DC motors and stepper motors are driven by microcontroller through L298N Dual H-Bridge Motor Controller Modules. These modules are compact and can be used with a variety of microcontrollers. It features a powerful L298N motor driver module with a heavy duty heat sink, powerful enough to drive motors from 5-35V at up to 2A peak.

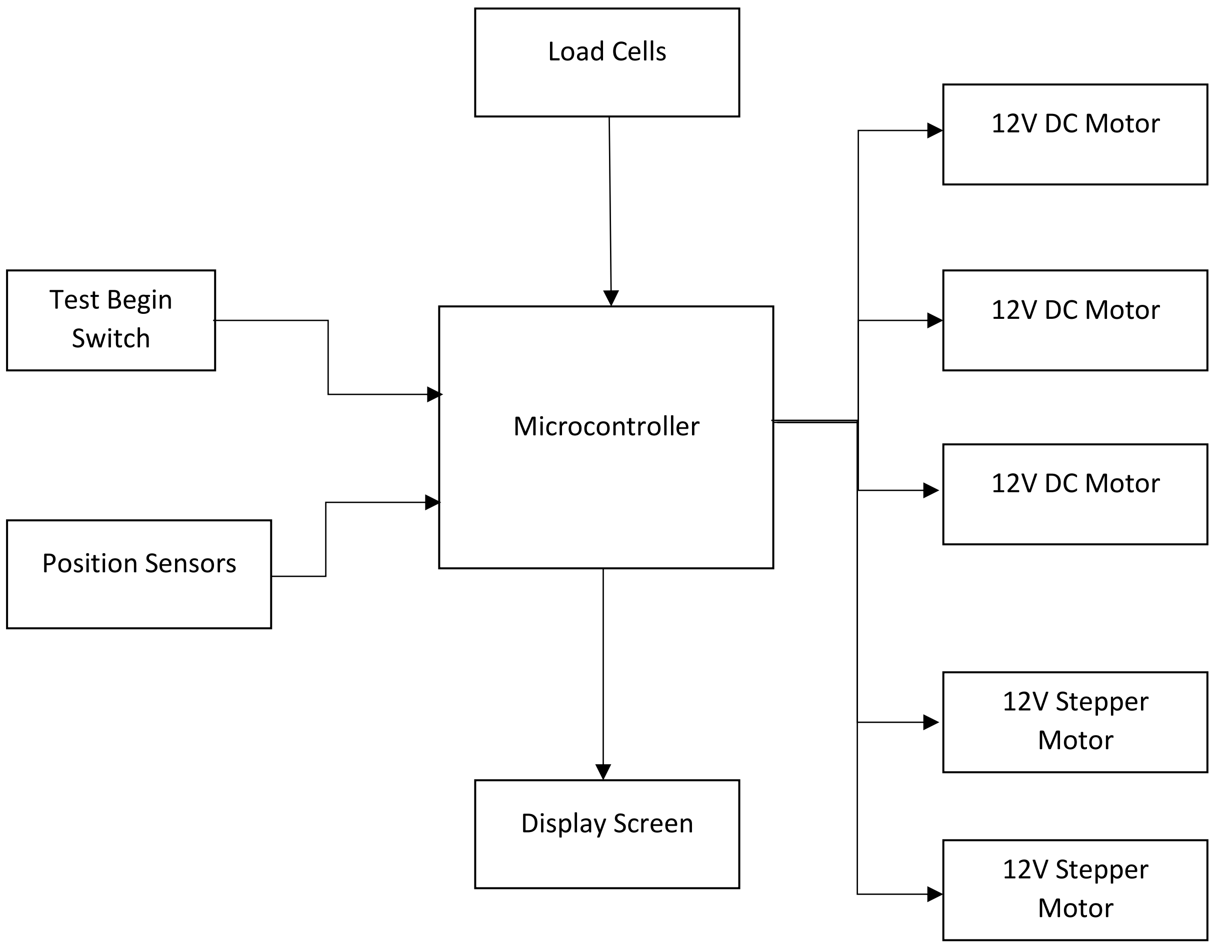

Figure 14: Schematic Diagram of Electronics and Controls

Load cells are interfaced through a small breakout board for the HX711 IC that allows load cells to be read easily to measure weight. By connecting the amplifier to microcontroller, the changes in the resistance of the load cell can be read, and with some calibration very accurate weight measurements are obtained. The HX711 uses a two-wire interface (Clock and

Data) for communication. Load cells use a four-wire Wheatstone bridge configuration to connect to the HX711. These are commonly colored RED, BLK, WHT, GRN and YLW. Each color corresponds to the conventional color coding of load cells as follows:-

- Red (Excitation+ or VCC)
- Black (Excitation- or GND)
- White (Amplifier+, Signal+ or Output+)
- Green (A-, S- or O-)
- Yellow (Shield). This pin acts as an optional input that is not hooked up to the strain gauge but is utilized to ground and shield against outside EMI (electromagnetic interference).

An ER-OLEDM024-1G is used as a graphics display for real-time output of test results to operator. It is 2.4 inch 128x64 green pixels OLED display with adaptor board with a simplistic design. The controller IC SSD1305, communicates via 6800/8080 8-bit parallel and I2C/4-wire serial interface. Because the display makes its own light, no backlight is required. This reduces the power required to run the OLED. When the systems turns on, the graphics screen indicates to the operator that the machine is homing. After the homing is complete, test results progress and machine decision of PASS or FAIL also displays on the screen. Real-time load cell data can also be seen on the display during the test process.

CHAPTER 4 – RESULTS AND DISCUSSION

4.1 Software Analysis and Simulation

4.1.1 Solidworks *Premium* 2015 was used for designing and simulation of the machine and its various parts and subassemblies. The design process of various part and sub–assemblies was modular. Therefore, when the entire assembly was put together it was bound to run well in a simulation. The simulation included fitment of parts, sizing of fasteners according to commercial availability in local market, expertise of available workmanship in workshop and the machinery in hand.

4.1.2 The simulation of entire machine included some 108 parts, big and small, put together in the form of individual models and sub-assemblies. This warranted the need of a computing machine with not only high computational power but an excellent 3D graphics acceleration handling capability. To address this problem, a high-end dedicated computational machine was employed which had the capability of faster working with high computational performance.

4.1.3 The approach to the simulation was three folds:-

- Small individual parts were designed and simulated for compatibility and manufacturability. Bigger parts were designed and simulated separately. They were also revisited during and after manufacturing process for minor changes of size and fitment.
- Smaller parts were combined into mid-size sub-assemblies and were tested and simulated one by one. Numerous changes had to be made in order for the workmanship to keep up the nature of job.
- Finally, all the parts and sub-assemblies were put together in a master file and simulated. Since all the loading tests had been performed on sub-assemblies, the simulation of final assembly of machine was checked only for synchronous and simultaneous actions of various functioning parts.

4.2 Practical Analysis and Results

The machine was put through various runs for practical testing of needle holders. The demonstration was organized in the quality assurance section of the industry in the presence of expert supervisors and floor managers. For this testing, numerous test pieces were provided by the industry duly marked as PASS and FAIL to run through the machine. This marking was done through existing manual procedure followed by the skilled workers.

The machine demonstrated 95% accuracy of results. The remaining 5% test pieces were declared FAIL by the machine due to limited slippage of thread during the testing, whereas the manual skilled workers had declared those test pieces as PASS. The pieces were separated and re-inspected by the supervisor of skilled workers and were declared as truly FAIL. Those pieces were returned to reworking stations for necessary adjustments.

Due to paucity of time, the scope of project was limited to one H-post working with one T-post with intervention one operator for loading and unloading of needle holder. It was proposed that the modules could be cascaded in future for achievement of a comprehensive automation solution.

4.3 Observations and Rectification

4.3.1 The needle holder is manufactured through manual forging and hand-working processes. Therefore, mostly no two pieces are identical and there can be size variation on almost all contours of the needle holder. It is pertinent to mention that the machine was designed to perform a delicate task and any variation of more than ±0.1mm could cause parts to become misfits. Due to this factor, size flexibility had to be catered for in following parts of machine:-

- In H-post, the lugs which hold the thumb rings had to be flexible to accept different sizes of thumb rings. Due to this factor, a slot was introduced underneath the static ring which could hold the static ring of varying sizes and prevent tipping over when pressed.
- Similarly, the slot which was required to hold the front of the needle holder had to be kept flexible to adjust various thicknesses of needle holder.

4.3.2 The manufacturer proposed that the machine should be flexible enough to be able to test various sizes of needle holders. The observation pointed towards one-machine solution to all the quality testing needs of the industry. Various sizes of needle holders could be incorporated in the machine by using different sizes of replaceable holding jigs in the H-post. Therefore, seven different sized holding jigs could be appended with the machine for seven different sizes of needle holder. The proposal would entail replacing respective size gripping jig for a given lot of needle holders, and then replacing the appropriate size gripping jig for next lot of needle holders.

4.3.3 It was observed that the design with two thread gripper posts consumed 8-10 inches of suturing thread per instance of test. This consumption could be reduced in two ways as follows:-

- Use of a relatively economical alternative test thread. For this numerous thread from local market were explored but no suitable alternative could be found.
- Modifying the design such that instead of loading thread around three posts, it should unwind from one and get wound under tension on the second. A test prototype was fabricated to address this aspect but it could not be meet required test parameters. The main problem with this solution was that the thread which already had been crimped by needle holder got weakened and broke when pulled by the second winding post. As a result there had to be a noticeable operator intervention to load the thread back on to the winding post.

4.4 Future Work

The needle holder thread tension testing machine designed and fabricated in this project has been commissioned successfully in M/S Dr Frigz International (Pvt) Ltd, Sialkot. A copy of certificate to this effect, awarded by the industry, has been included as Appendix A. Two patents have also been filed with Intellectual Property Organization of Pakistan, whose copies have been attached as Appendix B.

This machine can be rightly termed as first industrial-scale working model. It is destined to improve many folds over revisions and addition of modules. Some of the future works are suggested below:-

4.4.1 The thread, braided silk suture, is currently being used for testing of needle holders. This thread is expensive and can be replaced with a suitable economical alternative. However, the alternative thread must have similar physical and mechanical properties to those of actual thread.

4.4.2 Fixtures for H-post may be designed and fabricated which could hold various different sizes of needle holder. These fixtures should be designed keeping in mind the existing machine’s specifications and schematics.

4.4.3 The control system of machine is based upon AVR Arduino Mega microcontroller board and affiliated electronics. Arduino is a good microcontroller for prototyping purposes, however for industrial scale applications PIC microcontroller is more robust. PIC microcontroller could be customized for minimal peripherals thereby keeping the architecture simple and practicable.

4.4.4 There is a need to work on the unwinding and winding thread gripper posts. But the new design has to exclude operator's intervention for testing of at least one complete lot of needle holders (360 pieces). In addition, the load cell connection would be spring loaded, with its tension adjusted to thwart any chances of thread breakage during testing of needle holders.

4.4.5 The machine has to take a final shape of a comprehensive autonomous automation solution which has been depicted in Figure 4 of Chapter 3. This entails cascading of T-posts and H-posts and creating a super-control system of the entire automation system, i.e., one microcontroller running instructions through many microcontrollers.

CHAPTER 5 – CONCLUSION

Biomedical Engineers are putting in efforts and researches in bringing innovative process automation techniques to healthcare industry at par with a good quality engineering practices. Much of the design research and implementation has been carried out and literature is abundantly available on the subject of indigenous process automation and development. However, very little or no work has been undertaken on understanding, designing and development of the same. There is immense potential in research, implementation and indigenous development of machine parts, control electronics and synchronously operating sub-assemblies.

Engagement of market through skillfully carved student projects brings about trust of industry in academia. One working mechanism can lead to another, until entire machinery of industry has its engagement into research and development of new machines and automation solutions.

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COMPLETION CERTIFICATE FROM INDUSTRY

Dr. Frigz International (Pvt) Ltd.

RM # S-5

Manufacturer, Exporter & Importer Of Surgical, Dental & TC Instruments
ISO 9001, ISO 13485, cGMP,CE Mark Certified Products

TO WHOM IT MAY CONCERN

This is to certify that Mr **Muhammad Kashan Siddiqui** has successfully completed his project titled "Design and fabrication of an industrial thread tension-testing machine which provides a quality-testing solution to manufacturer of suturing Needle Holder" in our company Dr. Frigz International (Pvt) Ltd Sialkot, with reference to fulfilment of his MS Biomedical Engineering degree in School of Mechanical and Manufacturing Engineering, National University of Sciences and Technology (NUST), Islamabad.

All necessary details were provided from our side, along with guidance and assistance to him, under technical auspices of Mr **Usman Daud Sair**, Director of HR & Finance, Dr. Frigz International (Pvt) Ltd from August 2016 to June 2017.

Mr Muhammad Kashan Siddiqui is a sincere and hardworking student, with remarkable engineering concepts and design skills. We wish him the very best in all his professional endeavors. We hope for an enhanced and continued industry-academia nexus in future as well.

With profound regards,

For & on behalf of

Dr. Frigz International (Pvt) Ltd.

Dr. Frigz International (Pvt) Ltd. Sialkot

Usman Daud Sair
Director HR & Finance

Dated : 14 June 2017

Dr. Frigz International (Pvt) Ltd.
Airport Road, Gohad Pur,
Sialkot- 51310 Punjab.
Pakistan

E-mail: info@frigzinternational.com
Web: www.frigzinternational.com
NTN # 1427205-9
Sales Tax #: 09-05-9018-921-46

Tel.Off: +92 - 52 - 4262703
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PATENT APPLICATION FORM P-1A

Form P-1A

Fee: Rs.

Patents Ordinance, 2000

Application for patent when the true and first inventor is NOT a party to the application
(Section 13(1) (Rule 8(1))
(To be accompanied in duplicate by a Provisional Specification on Form P-3 or the Complete Specification on Form P-3A)

Insert (in full) the name, address, and nationality of the applicant or applicants.

~~I~~ (or we) Murtaza Najabat Ali (Pakistani) NUST H-12 Campus Islamabad
M Kashan Siddiqui (Pakistani) NUST H-12 Campus Islamabad

Insert title of the invention.

hereby declare that: - Industrial Automation Solution for Quality-Testing of Suturing Needle Holder

Insert name.

(i) I am in possession of an invention for ____________________;

Insert (in full) name, address, and nationality of inventor.

(ii) that I (or we)(or the said)(____________________) claim to be the assign of (or the legal representative of) ____________________

State here whether the specification accompanying this form is form is "provisional" or "complete".

who claim(s) and is (are) believed to be the true and first inventor(s) thereof;
(iii) that the invention is not in use in Pakistan by any other person;
(iv) that the ____________________specification filed with this application is, and any amended specification which may hereafter be filed in this behalf will be, true of the invention to which this application relates;
(v) that the facts and matters stated herein are true to the best of my (or our) knowledge, information and belief.

Insert number of sheets of the Description, Claim(s), Abstract, and Drawing(s).

(vi) that following are particulars of my application,-

Description:	04
Claim (s):	03
Abstract:	01
Drawing (s):	08

Insert address for service in Pakistan.

Address for service in Pakistan:

~~I~~ (or we) humbly pray that a patent may be granted to ~~me~~ (or us) for the said invention.

Insert name, designation and address of the signatory. In case of Agent, also include latest tele-communication details.

Dated this __________ day of ____________________, 20___

Signature ____________________

Name: Murtaza Najabat Ali
Designation: Assistant Professor

Address: NUST H-12 Campus Islamabad

To
Controller of Patents
The Patent Office
Karachi

PATENT APPLICATION FORM P-28

Form P-28
To be stamped
under the stamp Act.

Patents Ordinance, 2000
Form of Authorization to Agent.
(Section 81)(Rule 55)

Insert particulars of the case.

IN THE MATTER OF Industrial Automation Solution for Quality-testing of Suturing Needle Holder.

Insert (in full) the name, address, and nationality.

~~I~~ (or we)
Murtaza Najabat Ali (Pakistani) NUST H-12 Campus Isb.
M Kashan Siddiqui (Pakistani) NUST H-12 Campus ISB.

hereby authorize

Insert name, address and communication details of the Agent.

NUST IP Office
NUST Main Campus
Sector H-12
Islamabad.

to act as my (or our) Agent and to perform the functions, acts and deeds deemed permissible by the Ordinance and the Rules and to receive all notices, requisitions and communications until further notice.

Strike out if not required.

Insert name of Agent whose authority is cancelled.

And I (or we) revoke the N/A previous authority given by me (or us) to N/A

in this matter.

Insert name, designation and address of the signatory. In case of Agent, also include latest tele-communication details.

Dated this ______ day of ______, 20___

Signature [signature]

Name: Murtaza Najabat Ali
Designation: Assistant Professor

Address: NUST Main Campus
Sector H-12 Islamabad.

STAMP AFFIXED.
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Dated 19/7/17
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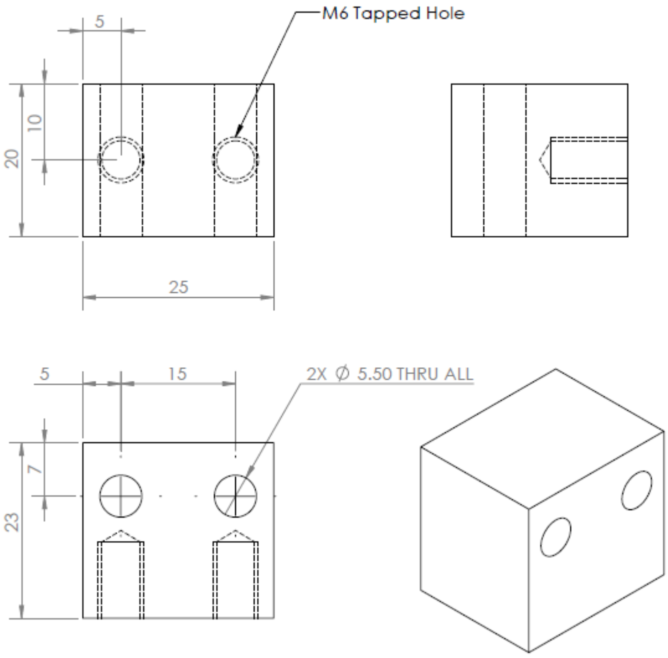
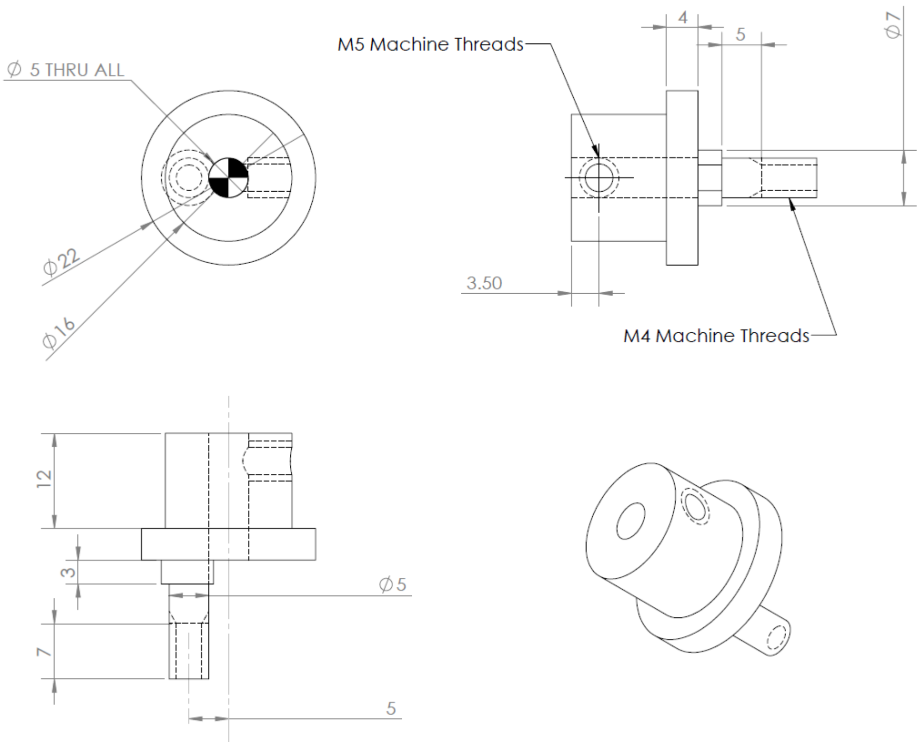
ENGINEERING DRAWINGS – PARTS AND ASSEMBLIES

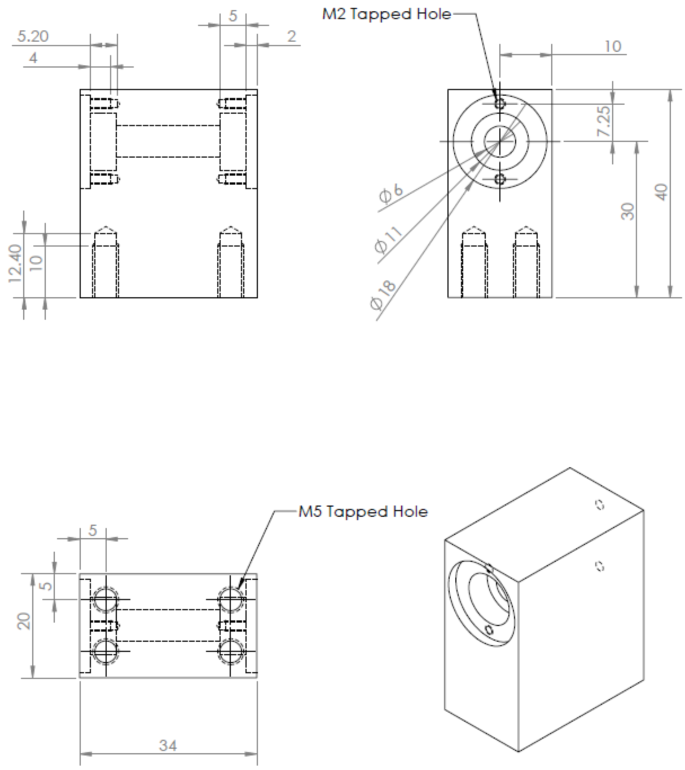
Load Cell Anchor Block



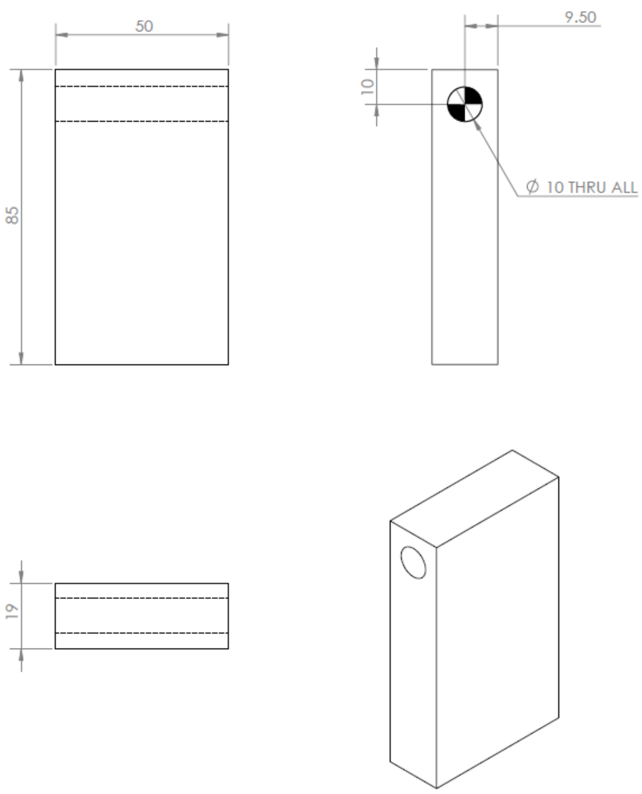
DC Motor Drive Pulley



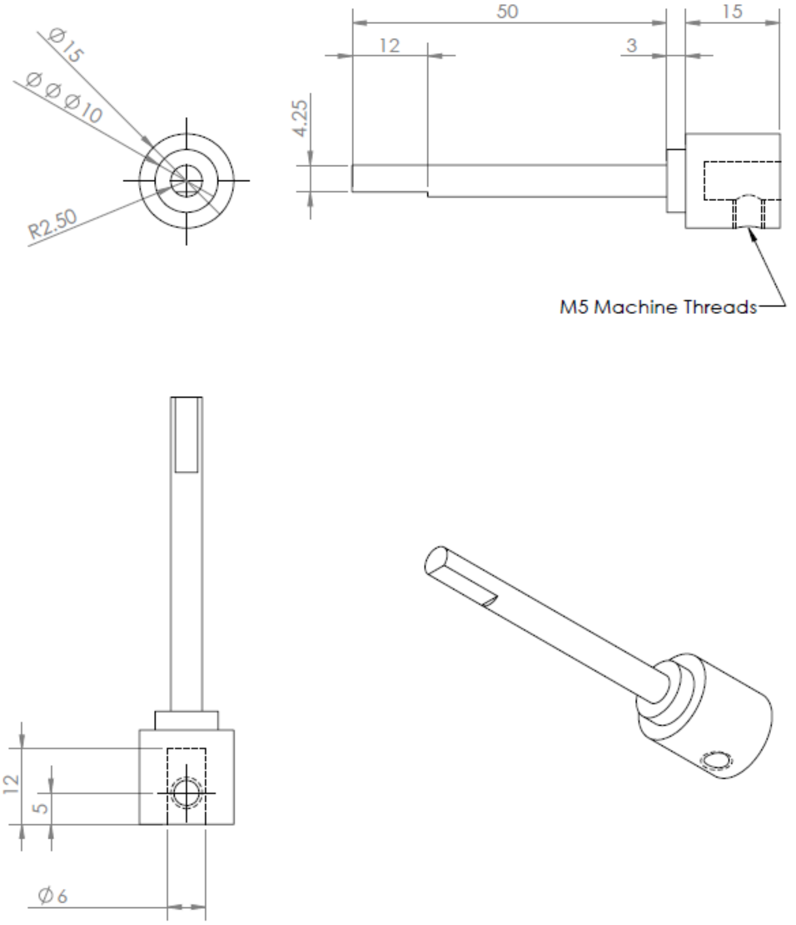
DC Motor Bearing Block



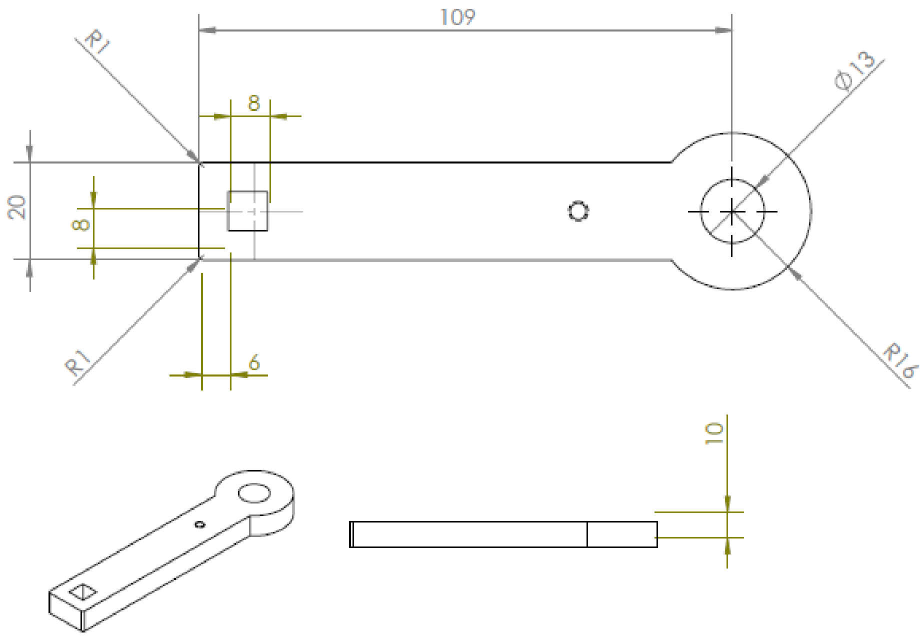
Guide Rod Journal



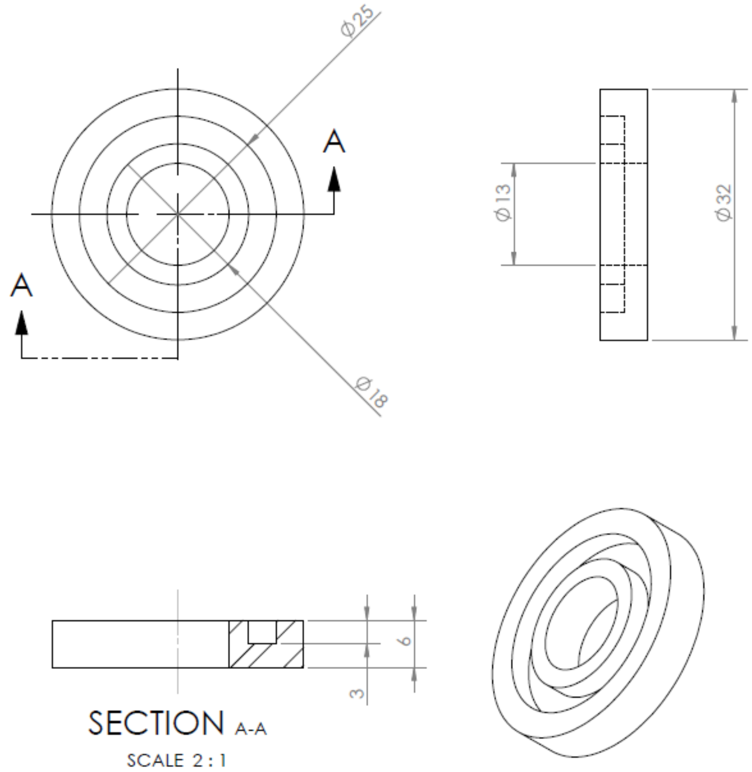
DC Motor Block Shaft



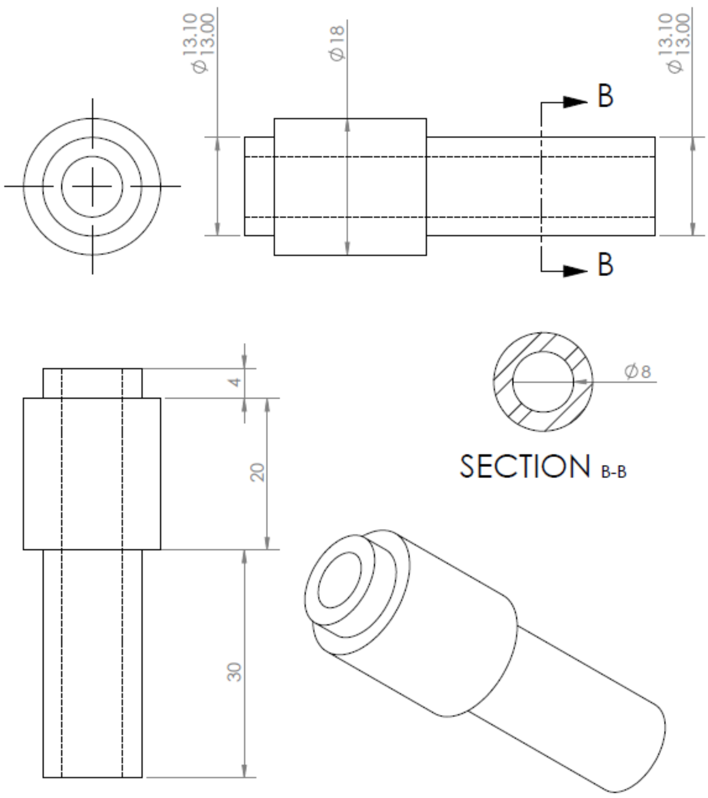
Thread Gripper Base Plate



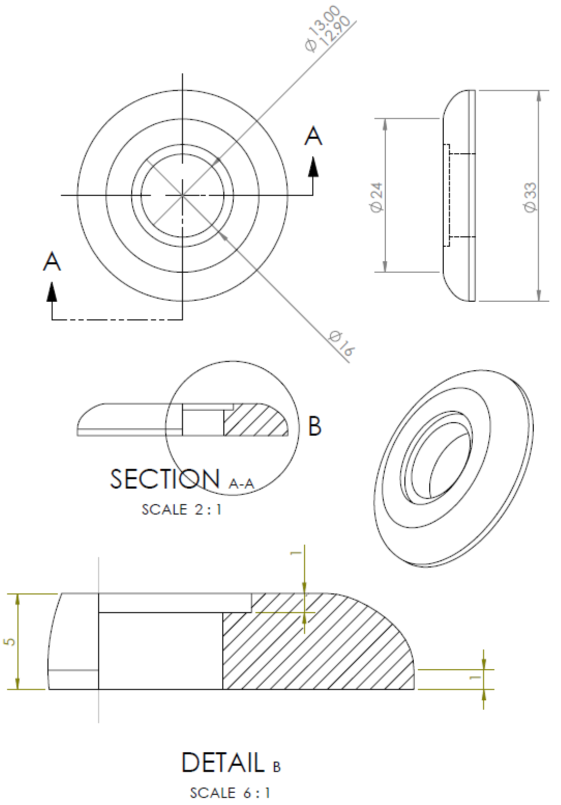
Follower Spring Cup



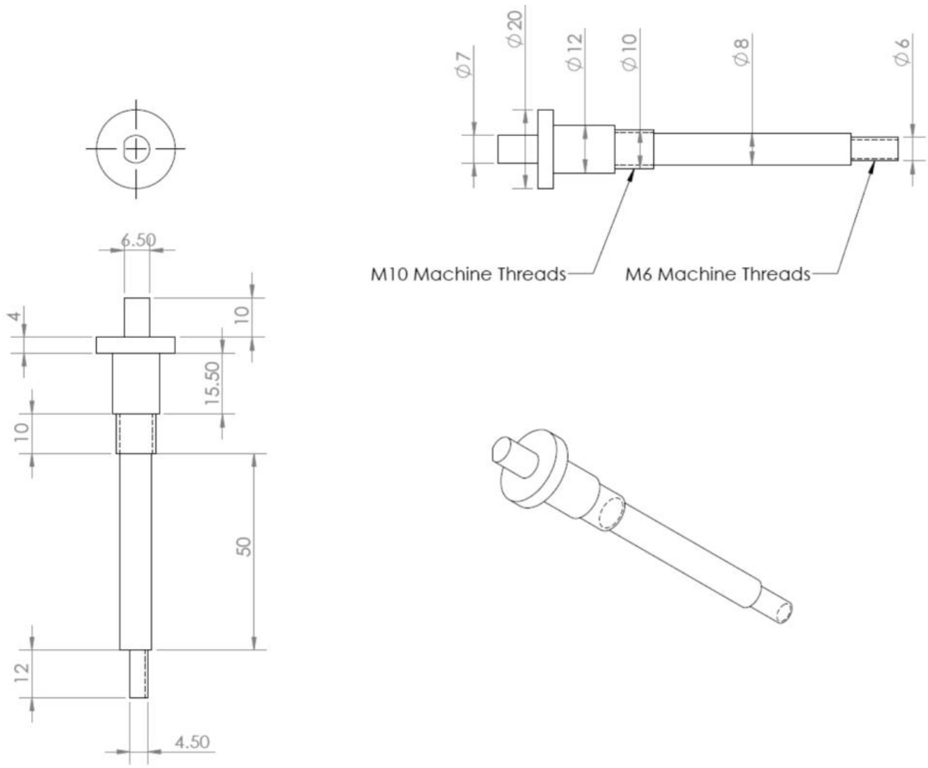
Barrel Pipe



<u>Lower Round Plate</u>



<u>Thread Loader Shaft</u>



ARDUINO CODE

Main Sketch

```
#include "HX711.h"
#include <Stepper.h>
#include <Servo.h>
#include <UTFT.h>
extern uint8_t SmallFont[];
extern uint8_t BigFont[];
extern uint8_t CalibriBold32x48[];

UTFT myGLCD(ST7735,24,23,22,26,25);//(<model code>, SDA, SCL, CS, RST[, RS]);
extern unsigned const int LOGO[0x2B34] PROGMEM;

HX711 cell_1(3, 2);

const int stepsPerRevolution = 200;

Stepper Stepper_lower(stepsPerRevolution, A4,A6,A5,A7);
Stepper Stepper_thread(stepsPerRevolution, A8,A10,A9,A11);
Stepper Stepper_upper(stepsPerRevolution, A12,A14,A13,A15);
Servo myservo;
//-----------------------------------------------------------------------------------------------------------

//VARIABLES

long temp1 = 0;
long temp2 = 0;
long val_1 = 0;
long val_2 = 0;
long xx = 0;
long yy = 0;
long maxxx = 0;
long value = 0;
float count = 0;
int reader = 0;
int threshold = 100;
int Result = 0;

int pos = 0;


//-------------------------------------------------------------------------------------------------



//PINS DEFINITION

const int Plunjar = 8;
//const int Relay_2 = 11;

const int Start = 44; //Front Limit Switch
//const int Button_1 = 46;
const int Upper_switch = 43;
```

```
const int Lower_switch = 45;

//----------------------------------------------------------------------------------------------

// FUNCTIONS


void Display_Logo(void);
void Display_Homing(void);
void Display_Result(void);
void Display_Busy(void);
void Homing_upper(void);
void Homing_lower(void);
void Main_Screen(void);
void Load_Cell(void);
void baseline(void);
void Stop_upper(void);
void Stop_lower(void);
void Stop_thread(void);
void servo_open(void);
void servo_close(void);
void servo_start(void);
int  Function(void);

//-------------SETUP--------------SETUP------------SETUP--------------SETUP-------------SETUP------------------------------

void setup()
{

 Serial.begin(9600);
 myservo.attach(46);
 pinMode (Plunjar, OUTPUT);
 //pinMode (Relay_2, OUTPUT);
 //pinMode (Button_1, INPUT);
 pinMode (Start, INPUT);
 pinMode (Upper_switch, INPUT);
 pinMode (Lower_switch, INPUT);

 digitalWrite (Plunjar, HIGH);
 //digitalWrite (Relay_2, HIGH);
 Stepper_upper.setSpeed(100);
 Stepper_thread.setSpeed(20);
 Stepper_lower.setSpeed(30);

  myGLCD.InitLCD();
 // Display_Logo();
  //delay(2000);

  myGLCD.fillScr(0, 0, 0);
//  myGLCD.setFont(CalibriBold32x48);
//  myGLCD.setBackColor(0, 0, 0);
//  myGLCD.setColor(0, 255, 0);
//  myGLCD.print("100", CENTER, 60);
//  delay (10000);

  Homing_upper();
  delay (500);
```

```
  Homing_lower();
  delay(500);
  servo_start();
  Main_Screen();
  delay(500);
  //baseline();

}

//--------------------LOOP------------LOOP-------LOOP--------LOOP-----------LOOP------------LOOP--------------LOOP---------
----------------


void loop()
{
  while (digitalRead(Start)== LOW)
  {
   Display_Busy();
   digitalWrite(Plunjar, HIGH);
   servo_open();
   Stepper_upper.step(2300);
   digitalWrite(Plunjar, LOW);
   digitalWrite(Plunjar, HIGH);
   Stop_upper();
   delay(1000);
   if(Function() == 1)
     {
       digitalWrite(Plunjar, HIGH);
       servo_open();
       delay(1000);
       Stepper_upper.step(-600);
       digitalWrite(Plunjar, LOW);
       digitalWrite(Plunjar, HIGH);
       Stop_upper();
       delay(1000);
        if(Function()== 1)
        {
          digitalWrite(Plunjar, LOW);
          servo_open();
          delay (1000);
          Stepper_upper.step(-800);
          digitalWrite(Plunjar, LOW);
          digitalWrite(Plunjar, HIGH);
          Stop_upper();
          delay(1000);
          if(Function()== 1)
            {
              Result = 4;
            }
            else
            {
            Result = 3;
            Stepper_upper.step(-600);
            Stop_upper();
            }
         }
         else
```

```
      {
       Result = 2;
       Stepper_upper.step(-800);
       Stop_upper();
      }
   }
   else
   {
    Result = 1;
    Stepper_upper.step(-2300);
    Stop_upper();
   }
    Display_Result();
  }
//Main_Screen();
}
//-----------------------------------------------------------------------------------------------------------------

void Display_Logo()
{
 myGLCD.setFont(SmallFont);
 myGLCD.fillScr(255, 255, 255);
 myGLCD.setContrast(24);
 myGLCD.drawBitmap (8, 25, 140, 79, LOGO, 1);
}

void baseline()
{
temp1 = cell_1.read_average(20);
//temp2 = cell_2.read_average(20);
}
void Homing_upper()
{
 Display_Homing();
 while(digitalRead(Upper_switch) == HIGH)
 {
  digitalWrite(Plunjar, HIGH);
 Stepper_upper.step(-20);
 delay (1);
 }
 digitalWrite(Plunjar, LOW);
 digitalWrite(Plunjar, HIGH);
 Stop_upper();
  }
 void Homing_lower()
{
 Display_Homing();
 while(digitalRead(Lower_switch) == HIGH)
 {
  Stepper_lower.step(-5);
  delay(1);
  }
//  stepper_lower.step(-50);
 Stop_lower();
}
```

```
void Display_Homing()
{
  myGLCD.fillScr(0, 0, 0);
  myGLCD.setFont(BigFont);
  myGLCD.setBackColor(0, 0, 0);
  myGLCD.setColor(0, 255, 0);
  myGLCD.print("HOMING", CENTER, 60);
}
void Main_Screen()
{
  myGLCD.fillScr(0, 0, 0);
  myGLCD.setFont(BigFont);
  myGLCD.setBackColor(0, 0, 0);
  myGLCD.setColor(255, 0, 0);
  myGLCD.print("READY", CENTER, 60);
}
void Display_Cell()
{
  //Load_Cell();

  myGLCD.setFont(BigFont);
  //myGLCD.setBackColor(0, 0, 0);
  myGLCD.setColor(0, 255, 0);
  myGLCD.print("        ", CENTER, 60);
  myGLCD.setColor(0, 255, 0);
  myGLCD.printNumI(yy, 20, 60);
//  myGLCD.setColor(0, 255, 0);
//  myGLCD.printNumI(maxxx, 80, 60);
}
void servo_start()
{
   for(pos = 0; pos <= 180; pos += 1) // goes from 0 degrees to 180 degrees
  {                                  // in steps of 1 degree
    myservo.write(180);              // tell servo to go to position in variable 'pos'
    delay(15);                       // waits 15ms for the servo to reach the position
  }
}
void servo_open()
{
  for(pos = 0; pos <= 170; pos += 1) // goes from 0 degrees to 180 degrees
  {                                  // in steps of 1 degree
    myservo.write(170);              // tell servo to go to position in variable 'pos'
    delay(15);                       // waits 15ms for the servo to reach the position
  }
}
 servo_close()
{
  for(pos = 170; pos>=0; pos-=1)     // goes from 180 degrees to 0 degrees
  {
    myservo.write(0);                // tell servo to go to position in variable 'pos'
    delay(15);                       // waits 15ms for the servo to reach the position
  }
}


void Load_Cell()
{
```

```
  val_1 = cell_1.get_value();
  yy = abs((val_1-temp1)/1000);
//  val_2 = cell_2.get_value();
//  xx = abs((val_2-temp2)/1000);
  //Display_Cell();

//  Serial.print ( "VALUE1: ");
//  Serial.println(yy);
//  Serial.print("\t VLAUE2:\t");
//  Serial.println(xx);
//  delay(100);
}

void Display_Result()
{
  myGLCD.fillScr(0, 0, 0);
  myGLCD.setFont(CalibriBold32x48);
  myGLCD.setBackColor(0, 0, 0);
  myGLCD.setColor(0, 255, 0);
  if (Result==1)
  {
    myGLCD.print("1", CENTER, 40);
    delay (1000);
  }
  else if (Result==2)
  {
    myGLCD.print("2", CENTER, 40);
    delay (1000);
  }
   else if (Result==3)
  {
    myGLCD.print("3", CENTER, 40);
    delay (1000);
  }
   else if (Result==4)
  {
    myGLCD.print("4", CENTER, 40);
    delay (1000);
  }
}
void Display_Busy()
{
  myGLCD.fillScr(0, 0, 0);
  myGLCD.setFont(BigFont);
  myGLCD.setBackColor(0, 0, 0);
  myGLCD.setColor(255, 0, 0);
  myGLCD.print("BUSY", CENTER, 60);
}
int Function()
{
  int RT = 0;
  digitalWrite(Plunjar, LOW);
  delay(200);
  Stepper_thread.step(30);
  digitalWrite(Plunjar, HIGH);
  Stop_thread();
  delay(1000);
```

```
  servo_close();
  delay(1000);
  Load_Cell();
  value = yy;
  //Display_Cell();
  Stepper_lower.step(30);
  delay(1000);
  Load_Cell();
  //Display_Cell();
  maxxx = yy-value ;
  delay(500);
  Stepper_lower.step(-30);
  Stop_lower();
  servo_open();
    if (maxxx > threshold)
  {
    RT = 1;
  //  Display_Cell();
  }
  else
  {
   RT = 0;
  }
  return RT;
 }

 void Stop_lower()
 {
  digitalWrite(A4, LOW);
  digitalWrite(A5, LOW);
  digitalWrite(A6, LOW);
  digitalWrite(A7, LOW);
}

void Stop_thread()
{
  digitalWrite(A8, LOW);
  digitalWrite(A9, LOW);
  digitalWrite(A10, LOW);
  digitalWrite(A11, LOW);
}
void Stop_upper()
{
  digitalWrite(A12, LOW);
  digitalWrite(A13, LOW);
  digitalWrite(A14, LOW);
  digitalWrite(A15, LOW);
}
```

HX711 – CPP File

```
//#include <Arduino.h>
#include "HX711.h"

HX711::HX711(byte dout, byte pd_sck, byte gain) {
	PD_SCK  = pd_sck;
	DOUT    = dout;

	pinMode(PD_SCK, OUTPUT);
	pinMode(DOUT, INPUT);

	set_gain(gain);
}

HX711::~HX711() {

}

bool HX711::is_ready() {
	return digitalRead(DOUT) == LOW;
}

void HX711::set_gain(byte gain) {
	switch (gain) {
		case 128:			// channel A, gain factor 128
			GAIN = 1;
			break;
		case 64:		// channel A, gain factor 64
			GAIN = 3;
			break;
		case 32:		// channel B, gain factor 32
			GAIN = 2;
			break;
	}

	digitalWrite(PD_SCK, LOW);
	read();
}

long HX711::read() {
	// wait for the chip to become ready
	while (!is_ready());

	byte data[3];

	// pulse the clock pin 24 times to read the data
	for (byte j = 3; j--;) {
		for (char i = 8; i--;) {
			digitalWrite(PD_SCK, HIGH);
			bitWrite(data[j], i, digitalRead(DOUT));
			digitalWrite(PD_SCK, LOW);
		}
	}
```

```
	// set the channel and the gain factor for the next reading using the clock pin
	for (int i = 0; i < GAIN; i++) {
		digitalWrite(PD_SCK, HIGH);
		digitalWrite(PD_SCK, LOW);
	}

	data[2] ^= 0x80;

	return ((uint32_t) data[2] << 16) | ((uint32_t) data[1] << 8) | (uint32_t) data[0];
}

long HX711::read_average(byte times) {
	long sum = 0;
	for (byte i = 0; i < times; i++) {
		sum += read();
	}
	return sum / times;
}

double HX711::get_value(byte times) {
	return read_average(times) - OFFSET;
}

float HX711::get_units(byte times) {
	return get_value(times) / SCALE;
}

void HX711::tare(byte times) {
	double sum = read_average(times);
	set_offset(sum);
}

void HX711::set_scale(float scale) {
	SCALE = scale;
}

void HX711::set_offset(long offset) {
	OFFSET = offset;
}

void HX711::power_down() {
	digitalWrite(PD_SCK, LOW);
	digitalWrite(PD_SCK, HIGH);
}

void HX711::power_up() {
	digitalWrite(PD_SCK, LOW);
}
```

HX711 Header File

```
#ifndef HX711_h
#define HX711_h

#if ARDUINO >= 100
#include "Arduino.h"
#else
#include "WProgram.h"
#endif

class HX711
{
	private:
		byte PD_SCK;	// Power Down and Serial Clock Input Pin
		byte DOUT;		// Serial Data Output Pin
		byte GAIN;		// amplification factor
		long OFFSET;	// used for tare weight
		float SCALE;	// used to return weight in grams, kg, whatever
	public:
		// define clock and data pin, channel, and gain factor
		// channel selection is made by passing the appropriate gain: 128 or
	64 for channel A, 32 for channel B
		// gain: 128 or 64 for channel A; channel B works with 32 gain factor
	only
		HX711(byte dout, byte pd_sck, byte gain = 128);

		virtual ~HX711();

		// check if HX711 is ready
		// from the datasheet: When output data is not ready for retrieval,
	digital output pin DOUT is high. Serial clock
		// input PD_SCK should be low. When DOUT goes to low, it indicates
	data is ready for retrieval.
		bool is_ready();

		// set the gain factor; takes effect only after a call to read()
		// channel A can be set for a 128 or 64 gain; channel B has a fixed 32
	gain
		// depending on the parameter, the channel is also set to either A or B
		void set_gain(byte gain = 128);

		// waits for the chip to be ready and returns a reading
		long read();

		// returns an average reading; times = how many times to read
		long read_average(byte times = 10);

		// returns (read_average() - OFFSET), that is the current value without
	the tare weight; times = how many readings to do
		double get_value(byte times = 1);

		// returns get_value() divided by SCALE, that is the raw value divided
	by a value obtained via calibration
		// times = how many readings to do
		float get_units(byte times = 1);
```

```
		// set the OFFSET value for tare weight; times = how many times to
	read the tare value
		void tare(byte times = 10);

		// set the SCALE value; this value is used to convert the raw data to
	"human readable" data (measure units)
		void set_scale(float scale = 1.f);

		// set OFFSET, the value that's subtracted from the actual reading
		(tare weight)
		void set_offset(long offset = 0);

		// puts the chip into power down mode
		void power_down();

		// wakes up the chip after power down mode
		void power_up();
};

#endif /* HX711_h */
```

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