DESIGN AND FABRICATION OF SURFACE TEXTURING MACHINE FOR CREATING MICRO PATTERNS

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DEPARTMENT OF MECHANICAL ENGINEERING

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DEDICATION

In appreciation of their unending love, support, and encouragement, we would like to dedicate our effort to our parents and instructors. To our supervisor, co-supervisor, and all the reputable teachers who helped us succeed.

May Allah Almighty bless and guard them all (Ameen).

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ABSTRACT

Surface texturing is one of the major research topics these days. Many techniques and machines are invented for this purpose. But those techniques and the machines are either not available in the market or are very expensive. These days, the Laser technology is being used for surface texturing but its operation and maintenance is not easy. And it's not cheap so most educational institutions cannot afford it for research purposes.

This project is aimed at providing a cheap and easy solution in the field of surface texturing. The goal of this project was to fabricate a CNC-based indenting machine for surface texturing. On the aluminium sheet or any soft substance, the indenter produces micro indent using a **400W BLDC Motor** and the patterns are produced by moving the workpiece through **NEMA 17 Stepper motors** in x and y directions, powered by **600W Supply**. The innovative aspect of this project is how the indentation process and CNC work are being combined. We will change surface texturing from the usual laser technology to mechanical.

LIST OF FIGURES

Figures **Page No**

LIST OF TABLES

Tables **Page no**

NOMENCLATURE

Abbreviation / symbol /Greek alphabet	Nomenclature
ASME	American Society of Mechanical Engineers
CNC	Computer Numerical Control
ρ	Density
=	Equals to
W	Watt
m	Meter
P	Power
I	Current
Amp	Ampere
V	Voltage
A	Area
N	Newton
F	Force
σ	Normal Stress
γ	Strain
τ	Shear Stress
P	Pressure
T	Torque
r	Radius

TABLE OF CONTENTS

CHAPTER -1 INTRODUCTION

Overview

Our project involves creating a CNC-based indentation machine prototype that use a steel ball tip indenter to create micro patterns on an aluminum sheet. The machine is powered by a 400W BLDC motor that provides the necessary force for the indenter to make precise indentations on the workpiece.

Our project is unique in that it is changing the traditional laser pattern making process into a mechanical process using the indentation mechanism. This could have potential benefits over laser pattern making, such as easy maintenance, low cost and easy to operate. Additionally, this project has potential applications in industries where micro patterns need to be made on metal surfaces.

The design and assembly of the indentation machine prototype, including the mechanical and electrical parts used, is the main topic of our thesis. We will go through possible uses for this technology as well as upcoming work that may be done to enhance the machine's functionality.

1.1 Background:

If we look back at how micropatterns were created, we can see the way technology has improved in every way. Today, surface texturing uses a variety of methods and technologies to make high-resolution, three-dimensional micropatterns on a wide range of materials that are useful in many fields and applications.

The initial techniques and ways of doing things took a lot of time and were hard to use. The old ways were cutting and etching. These were never used to make micropatterns. Instead, they were used for other things. Other methods include:

1. Photochemical etching
2. Electrochemical machining
3. Laser machining

1.2 Motivation:

Surface texturing machines are advanced machines that are used worldwide in industries. In Pakistan which is not a very high technology country have many issues related to the latest technology. Surface texturing is normally done through the laser technology and it has following drawbacks:

1. It is very expensive and can’t be affordable by every industry.
2. It is not easily available in the market
3. An expert person is required to run the machine at its full courses.

Considering the above provided information we thought of making a surface texturing machine that can create micro pattern through indentation process. In order to make this noval idea a reality we read many research papers just to find any relatable research that we can use in our project and consulted with many experts.

1.3 Problem Description:

Since a decade the laser technology is being used for surface texturing it is reliable and precise but like every other system the Laser technology has its drawbacks. It is more expensive, dangerous and difficult to operate. On the other hand, CNC is less expensive and easy to operate.

That’s why we thought of merging the indentation process with CNC to make a much more cheap and easily operatable machine that can fulfil the requirement. If we Talk about the fabrication of the machine, high quality materials and components are used to make machine tougher, increasing its lastingness. Several tests, calibrations and examinations are done to clarify all the errors, so that machine meets the desired specifications. Parts like tool post and connectors are carefully fabricated. It ensures that machine works smoothly and without any error.

1.4 Aim and Objectives:

Before creating this machine, we had several objectives in our mind. The main and primary objective of this machine was the fabrication of a well-organized, well-structured machine that allowed us to create micro patterns on soft aluminum sheet. This machine would be useful on variety of kind of materials and surface geometries. It allows customization and flexibility in the pattern. It is a CNC machine so no highly qualified person is required to operate this machine. Users without extensive technical knowledge can utilize it completely. Our main objectives were:

1. To design and fabricate a CNC based machine that can imprint dimples on a surface of a thin metal sheet with the help of indenter.
2. To manufacture an indenting mechanism with minimal cost.
3. To convert laser indentation into mechanical.

1.5 Scope and Application:

Surface texturing plays important role in now adays modern era of machines. It increases the overall performance and functions of variety of materials in industry. It has wide range of functions that help to enhance the components of miscellaneous industries. These micro patterns help us to improve the

- Friction reduction
- Wear resistance
- Lubrication
- Adhesion and many more surface related properties

To unlock all these betterments and create the micro patterns we made this surface texturing machine.

CHAPTER -2 LITERATURE REVIEW

Overview

This chapter includes the research that has been done related to this project. There are 25 research papers not directly linked but related, mentioned in the chapter.

2.1 ANTIK JAIN, VIVEK BAJPAI :

"Mechanical micro texturing and characterization on Ti6A14V for improving surface properties" was the topic of the study that Antik Jain and his partner Vivek Bajpai did. This recording was made on December 2, 2019. In their work, they used a micro-milling tool to make extruded center micro-Dimple textures on Ti6Al4V. Geometric values have been changed to see how the surface looks. A 3D profilometer was used to measure how rough the surface was and what shape it looked like in the middle. Also, formamide, diiodomethane, and ultra-pure water were used to measure equilibrium contact angles. Owen & Wendt, Wu, and LWAB were the three methods used to figure out the surface free energy (SFE). The SFE components calculated by the LWAB method tell us more about how textured surfaces behave when they get wet. The results show that the textures made are error-free, in good condition, and have sharp edges. Textured surfaces are more water-friendly, have a higher SFE, and have a rougher area surface in every shape. The size of the texture also changes the way the surface looks. All three methods were used to figure out the SFE for any collection of textures. The results of this study could help improve protein binding, cell growth, adhesion, proliferation, and osseointegration rates. They could also teach us more about how textured surfaces work [1]..

2.2 Xifang Zhang, Ningsong QU, Xiaolei Chen:

The study was based on the paper "Sandwich-like electrochemical micromachining of micro-dimples" by Xifang, Ningsong, and Xiaolei. This version came out on June 26, 2016. Micro-dimples have been added to different mechanical parts to improve friction and greasing in a wide range of industries. Through-mask electrochemical micromachining (TMEMM) is a potential method for making micro-dimples. Overcutting micro-dimples lowers the accuracy of machining in TMEMM. This study suggests a new method called sandwich-like electrochemical micromachining (SLEMM) to reduce the overcutting of micro-dots in diameter and improve the size uniformity of micro-dot arrays of values. Experiments show that when SLEMM is used instead of TMEMM, the micro-dimple width goes down from 124.3 to 109.0 m and the etch factor goes up sharply from 0.9 to 2.5. This shows that SLEMM should be able to improve the accuracy and localization of micro-dimple machining. Both TMEMM and SLEMM were able to make arrangements with 1500 microdots. The width and depth of the micro-dots in TMEMM grew from 120.8 and 11.0 m in the middle to 130.4 and 12.8 m at the edges. With SLEMM, on the other hand, the diameter and depth of the micro-dots at the middle of the workpiece surface were 109.0 m and 11.2 m, which is almost the same as at the edge. Because of this, SLEMM may also make the micro-dot groups more uniform in size. Lastly, you can use hexagons, ellipses, and squares with SLEMM to make different surface designs.[2]

2.3 T. PRATAP, K. PATRA:

The study was done by T. Pratap and K. Patra, and the version that was recorded on June 1, 2018 can be found here. "Mechanical micro-texturing of Ti-6A1-4V surfaces for improved wettability bio-tribological performances" is the title of the study they did. The goal of the current study is to use mechanically micro-textured surfaces to make the titanium alloy Ti-6Al-4V more wettable and improve its bio-tribological performance. On the Ti-6Al-4V surface, three different mechanical micro-tools, including a micro-flat-end mill, a micro-ball-end mill, and a micro-drill, are used to make circular micro-dimples with flat, semi-hemispherical, and conical end shapes, respectively. The effects of micro-textured geometries are determined based on surface roughness, microhardness, surface wettability, and coefficient of friction (COF). The contact angle of clean water is used to measure a surface's ability to hold water, while an in vitro hip joint prosthesis is used to measure COF. Semi-hemispherical end micro-dimpled surfaces are better for hip joint replacements because they are easier to wet and have a lower coefficient of friction. Using mechanical micromachining methods, titanium alloys and other similar biomaterials can have functional surfaces made on them. [3]

2.4 Matthew Horsfall, Matthew Simpson, Ramin Rahmani, Reza Nekouie-Esfahani:

Matthew Horsfall, Matthew Simpson, Ramin Rahmani, and Reza Nekouie-Esfahani did study on "Effect of surface texture positioning in grease-lubricated contacts" on April 19, 2023. It is well known that using artificially improved surfaces with good design, especially lubricated joints, can improve tribological performance in certain working conditions. We do not know much about how the tribological performance is affected by the textural features, which are not affected by the conditions in the contact footprint. A disc with no texture features was made, as were two discs with texture features in different places on the contact outline. The discs were tested in a ball-on-disc tribometer with actual contact settings, since these kinds of contacts can go through many different lubrication regimes as they work. The contacts were made smooth with grease. Textured features were found to make the friction worse right under the contact, compared to a smooth disc, by making the measured coefficient of friction go up. It has been shown that putting textures outside of the contact footprint track on the disc but very close to it can lower both the friction coefficient and wear.[4]

2.5 Ramana Reddy Annadi, Ismail Syed:

"Impact of multi-scaled surface textures on tribological performance of parallel sliding contact under lubricated condition" was the topic of a study by Ramana Reddy Annadi and Ismail Syed. This recording was made on March 23, 2023.

Sliding contacts with a single-scale textured pattern work well in situations with high speed and low load. Most machine-driven parts, on the other hand, work under changing speeds and loads. So, the idea of multi-scale textures came about to help deal with the changing working conditions. In this study, it is explained how to use a Nd:YAG laser to make textured surfaces with different sizes. Also, a pin-on-disc test rig was used to look at how the area density and texture depth of multi-scale textured surfaces affected tribological factors like frictional coefficient and wear rate. The results show that an area density of 0.3 and a texture depth of 10 m have better tribological features in most loading situations. Also, the results of the experiments match the results of the numbers.[5]

2.6 Shangshang Li, Hui Chen, Ting Luo, Guangchun Xiao, Mingdong Yi, Zhaoqiang Chen, Jingjie Zhang, Chonghai Xu:

Shangshang Li, Hui Chen, Ting Luo, Guangchun Xiao, Mingdong Yi, Zhaoqiang Chen, Jingjie Zhang, and Chonghai Xu all worked together on "Tribological properties of laser surface texturing modified GCr15 steel under graphene/5CB lubrication". This recording was made on April 20, 2022. On the surface of GCr15 steel, dimple-textured surfaces were made with square groups of different area density, diameter, and depth. For the friction and wear studies, liquid crystal 4-n-pentyl-4'-cyano biphenyl (5CB) and graphene solutions were used as lubricants. By changing the area density, diameter, and depth of the dimples, the lubrication performance of laser surface texturing was studied in a case where there was not enough lubrication. The mechanism of how laser surface texturing reduces friction and wear resistance was also first described. The dimple-textured surface works best for lubrication when the width is 100 m, the area density is 8%, and the dimple depth is 10 m. At this textured number, the friction coefficient is 0.031, which is 32.6% less than what it was on a smooth surface (0.046). The main goals of the surface's mechanism for reducing friction are to raise the load it can carry, store lubricant, reduce the area of contact, and provide secondary lubrication. XPS readings show that a chemical reaction layer forms on the surface of the steel when the graphene/5CB suspension rubs against the rough surface. The results of the study can be used to find theoretical directions for optimizing the geometric parameters of textures in different application cases.[6]

2.7 Binxun Li, Song Zhang, Jianfeng Li, Jiachang Wang, Shaolei Lu:

Binxun Li, Song Zhang, Jianfeng Li, Jiachang Wang, and Shaolei Lu all worked on "Quantitative evaluation of mechanical properties of machined surface layer using automated ball indentation technique" on January 23, 2020. Because machining changes the microstructure of the material, the top layer may have changes in its mechanical properties that are different from those of the rest of the material. It is very important to measure the mechanical properties of the machined top layer. In this study, the mechanical properties of the polished surface layer of AISI H13 steel made by hard milling were looked at using a nondestructive method called automated ball indentation (ABI) and a stress-strain microprobe. ABI tests were used to measure the real stress-strain curve, the yield strength, the ultimate tensile strength (UTS), the strain hardening exponent, and the Brinell hardness before and after hard milling. Also, the fracture toughness can be measured with the help of the continuum damage mechanics (CDM) study of the continuous loading and unloading curves. It seems to show that the ABI method can be used to test the mechanical qualities of a machined surface layer without doing any harm.[7]

2.8 C. Bernal, A. M. Camacho, M. M. Marín, B. de Agustina:

On July 24, 2013, C. Bernal, A. M. Camacho, M. M. Marn, and B. de Agustina all worked together to make this version. "Methodology for the evaluation of

3D surface topography in multiple indentation processes" was the subject of their study. Elementary pressing processes are fairly simple compression methods that are used in a wide range of industries. Still, putting these processes together is a new idea that is interesting from a technical point of view. CNC machines can do incremental forming processes with more flexibility, less force, and easier tools than traditional forging processes. The main goal of this work is to look at the three-dimensional shape that the repeated indentation process makes. With the help of shape parameters S a and S M, a predictive evaluation model has been made to measure the topography of the predicted surface and the amount of material moved based on the technological and geometrical aspects of the process. This model is based on the surface roughness values given in the standard ISO 4287. It uses a variety of tools to check the state of the 3D-formed surface. [8]

2.9 Handbook of Analytical Methods for Materials:

Micro indentation hardness testing, also called microhardness testing, is a way to measure how hard an object is on a small scale. An exact diamond indenter is used to make a mark on the material, which can weigh anywhere from a few grams to a kilogram. Using the test load and the length of the impression seen under a microscope, a hardness number can be calculated. The hardness numbers found are good predictors of a material's properties and how it will act in service. For many metals and alloys, you can convert micro indentation hardness numbers to tensile strength and other hardness scales, like Rockwell. People often use both a pyramid-shaped indenter with a square base (Vickers hardness scale) and a long, rhombohedral-shaped indenter (Knoop hardness scale) to make the indentations. For the set test load, the tester uses dead weights.[9]

2.10 Abdulaziz S. Alaboodi, Zahid Hussain:

Nearly all areas of engineering are using thin films and layers more and more. Thin film can be used to improve many things, such as magnetic, tribological, and strength properties. They are used in cutting tools, biomedical implants, and parts of engines that are prone to wear and corrosion, especially in the industrial field. During their working life, these coatings could fail, which would mean that the whole system would be lost. Because of this, it is important to look into the key loads that cause fractures. The nanoindentation technique is one of many ways to test how well a coating works in service, and it has been used many times for this reason. Also, if you want to get a lot of mechanical properties out of nanoindentation, you have to model it with good FEM tools.[10]

2.11 Infantantoabishek.J, Nandhagopal.V, Kesavan.S, Hakkim.M and Sivakumar:

A computer numerical control (CNC) is a device that uses computers to mill, cut, and engrave hard materials like steel, wood, plastic, and metal. Efficiency is made in many different fields. The two biggest benefits of a CNC engraving machine are cutting and accuracy. The goal of this project is to make CNC tools easier to use and cheaper. Wooden parts make up the system that does this. The Arduino is the major part of the design and development CNC, and it controls the X, Y, and Z movements of the CNC machine. The etched material was made by the machine's precise structure and 3-axis stepper motor setup. Some examples are carving on wood, drawing on printed circuit boards (PCBs), and etching on glass.[11]

2.12 Muhamad Izdhar Bin Zaki1, Kushendarsyah Saptaji1, Raden Dadan Ramdan, Tedi Kurniawan:

This study looked at how the angle of tilting the workpiece and the direction of the feed affected making a micro dimple pattern with ball end mill tools. The tests used an Al 6061-T6 aluminum workpiece, carbide ball end mill tools, and a CNC machine. There are three object tilt angles—00, 300, and 450—and two feed directions—the z-axis and the x-axis. With a scanning electron microscope (SEM) and a laser scanning confocal microscope, the formed micro dimple patterns were looked at and their shapes were measured. The results show that tilt (00) makes the edges of the dimples have less grit than tilt (00). Also, the tilt angle of the workpiece can stop an undercut from forming in the middle of the dimple. The workpiece tilt angle of 300 and z-axis feed direction gave better results than tilt angles of 0 and 450, with the ratio of diameter/depth being closer to the theoretical value.[12]

2.13 Cong Shen:

Surface texturing is a way to change the surface by making tiny designs on the parts that touch. This improves the tribological performance of sliding, lubricated systems. It has been found that the way textures are laid out geometrically has a big effect on how well they work. Some important geometric factors, like the area ratio and the depth-over-diameter ratio, have been found for textures that look like round bumps. The goal of this study is to use textures with new designs to improve the effect of surface texturing on reducing friction. Some new things to think about in texture creation are internal structure and geometric shape. Also, a new way of texturing piston rings is offered as a way to cut down on engine friction. Experiments and computer simulations are done on dimples with three different internal structures: a rectangle, an obtuse triangle, and an isosceles triangle. This is done to compare how well the dimples work. Using the Jakobsson-Floberg-Olsson (JFO) cavitation theory, the computer model predicts how much weight a surface can hold. It is found that the value of the cavitation pressure is important for using the JFO theory. Because of this, a study was done to figure out how to choose the cavitation pressure for steady-state lubrication. In the study of texture shape optimization, a numerical method based on the sequential quadratic programming (SQP) algorithm is used to find the best texture shape for different operating cases, such as unidirectional and bidirectional sliding and rotating. Experiments show that the result of the optimization for spinning is correct. For the use of surface texture in piston rings, a new design.[13]

2.14 Taizawa, Tatsuya Fukuda Tsuhiko:

A tabletop CNC stamping device was made so that thin sheets of work could be formed in fine, precise ways. Microembossing was used to study how imprinting worked during fine stamping for different film thicknesses. A micropatterned die was made with chemical etching and oxygen-plasma etching. The protective DLC coating on the tool steels was directly etched so that the design could be fine. This micropatterned die unit was put into a cassette mold-die for a pressing test. Thin film work-sheets made of aluminum with a purity of 99.9% and a thickness of 80 micrometers were used to show how imprinting works. We used a scanning electron microscope, a laser microscope, and a laser profilometer to figure out the shape of the imprints on these film sheets. By using oxygen plasma etching for different grooving widths from 3 to 11 micrometers and grooving pitches from 7 micrometers to 200 micrometers, a micro-grooving design was successfully imprinted onto a DLC coating. With the heat radiation device in mind, aligned square wedged patterns were cut into a metal sheet.[14]

2.15 Peter sugar, Jena Sugarova and Martin frnick:

In this experiment, the surface of tool steel of type 90MnCrV8 was textured using a laser. The 5-axis highly dynamic laser precision cutting center used a Lasertec 80 shape with a nano-second pulsed ytterbium fiber laser and a Siemens 840D CNC system. By turning, the first objects that were flat and round were given a texture. By putting spherical and ellipsoidal dimples in a regular pattern, you can make bumps that are different sizes and have different densities on the surface. Laser surface painting has been done in different ways based on pulse energy, pulse frequency, and laser speed scanning speed. Using a method called scamming electron microscopy, the morphology of ablated surfaces was studied. The results show that ns pulse fiber lasers cannot be used to create different surface structures for tri-biological change of metallic materials. We got these shapes by changing the processing conditions between surface ablation and surface remelting. On the bottom and sides of the dimples, there were always spots of molten metal and recast layers. In addition, the effect of laser beam parameters on the quality of the machined surface has been studied during laser machining of normal ellipsoidal and hemispherical dimple textures on parabolic and hemispherical surfaces.[15]

2.16 AARON GRECO, ASHLIE MARTINI, YUCHUAN LIU, CHIH LIN, and QIAN J. WANG:

The behavior of vibro-mechanically textured surfaces under rolling contact fatigue (RCF) in a point elastic hydrodynamic Examined is the state of lubrication (EHL). Small dimple signs (100 mm 100 mm) and big dimple signs (240 mm 100 mm) are compared to a sample that does not have any structure. Experimentally done RCF studies show that the textured surfaces have a lot fewer cycles to failure than the non-textured sample under high load, pure rolling conditions. These results are used to figure out the underground stress distribution, lubrication, and contact pressure conditions using numerical models. The lack of energy breaks down Trends seen in the real world and findings from simulations agree well. It is known that RCF exists. The size of the dimple and how much the crowd participates affect the performance.[16]

2.17 Advanced engineering materials

Since finely defined surface characteristics can reduce friction and/or wear no matter how the lubrication is working, the tribology group is very interested in surface texturing. Surface texture is especially interesting for machine parts because they can improve tribological performance under different lubrication conditions. Even though a lot of work has been done by both academics and the business world to add surface texturing to machine parts, there are still a lot of questions about the best way to create surface textures and how they affect the performance of the part. The goal of this review piece is to give an unbiased look at the current state of the art in surface texturing for machine parts, with a focus on piston rings, seals, roller bearings, and gears in particular. After a short introduction, the first part is about surface texturing in sliding parts (like piston rings and seals), while the second part is about surface texturing in rolling parts (like roller bearings and gears). Based on the original research from the literature, the last part gives more basic design rules for surface texturing in machine elements.[17]

2.18 S Wang, A Chen1, L Li and X Zhang

Laser surface texturing (LST) can greatly reduce the noise and shaking caused by sliding contacts. It can also improve the performance of different tri biological contacts in a big way. Using laser surface texturing technology, the surfaces of 16 pieces of stainless steel are given different surface patterns and textured area ratios. This is done so that the biological effects of this process can be studied. A common friction and wear testing machine (UMT-Tribo Lab) is used to test four different speeds of action in an oil-rich environment. The results of the experiments showed that sliding speed, texture depth, and texture area density had the least effect on the three biological properties of steel-steel sliding contacts. Researchers are looking into how laser surface texture affects the vibrations and noises that happen when two pieces of steel rub against each other when they slide against each other without oil. Laser surface roughness has a big effect on how well steel-steel dry slide contacts reduce noise in both the time and frequency domains. Because of this, laser surface texturing has a big effect on the tribological, vibrational, and other physical features of functional surfaces. To get the best tribological and vibrational performance, the functional surface texture should be adjusted by taking into account the effects of surface texture, lubrication, and contact state as a whole.[18]

2.19 Sergei M.Pimenov, Evgeny V.Zavedeev, Olga S.Zilova, Alexander P.Lepekhov, Beat Jaeggi, and Beat Neuenschwander

A-C:H:Si:O films, also called diamond-like nanocomposite (DLN) films, have a unique structure and great tribological properties that show up in a wide range of environmental and surface change conditions. In this study, we looked at how laser surface texturing and external factors, such as humid air, water and oil lubrication, and high temperatures, affected the tribological performance of DLN coatings. The surface was made rough with a 515 nm femtosecond laser. Comparative tests of DLN films sliding against different counter bodies (steel, Si3N4) in wet air and water showed that the film has low friction and wear under water, even though the water does not react chemically with the surface of the counter body. Even though there was more friction when moving with water as a lubricant, the wear rates of the film and Si3N4 ball in water were much lower than the values of 6.8 107 and 3.8 108 mm3/(Nm) in humid air. Laser surface texturing of DLN films was used to make groups of tiny craters. The next step was tribological testing with oil lubrication at different temperatures, running from 23 to 100 C. The softened friction performance of laser-textured films was better both at room temperature and at higher temperatures. The friction coefficient of the laser-textured material went down from 0.1 (the original film) to 0.083 and then to 0.068 at 100 C. Friction force microscopy was used in normal air to show that laser-structured surfaces have lower friction forces than the original surface when it comes to nano- and micro friction. The results show that DLN coatings have great tribological properties in many different situations and that femtosecond laser surface texturing can make these properties even better.[19]

2.20 Shunchu Liu, Qingyi Sai, Shuwen Wang, and John Williams

Circular pieces of stainless steel are given different shapes with the help of a picosecond laser. Using a tribo meter and a data capture and signal processing (DASP) system, researchers' study how laser surface textures affect vibration and tribology. Experiments have shown that the roughness of a surface can increase its resistance to wear, lower its coefficients of friction (COFs), and improve its dynamic performance. In this study, the surface with the best tri-biological and dynamical performance has tiny dimples with a width of 150 m or a textured area density of 25%.Compared to a surface without texture, one with 150 m-diameter circular dimples and 15% textured area lowers COFs by 27%, frictional vibrations by 95%, and frictional noise by 66%. By adding graphene to the lubrication oil, frictional vibrations and noise in sliding contacts can be cut down by a lot. The surface patterns make the lubricant even better at doing this.[20]

2.21 H.K. Tonshoff, C. Arendt, R. Ben Amor

Cutting solid steel is a topic that gets a lot of attention in science and industry today. Machine parts made of hardened steel are high-performance parts that are often used to their physical limits. Fine finishing is the last step in the production process. It can be done by cutting or grinding, and it has a big effect on how a part will work after it has been made. In general, the mechanics of chip removal in hard cutting and the thermomechanical effects of the work area are explained. Also, a number of models for chip removal in hard turning are shown and examined. These models summarize the basics of metallurgy and show how stress and temperature are distributed in the work area. In order to compare the cost-effectiveness of hard cutting and grinding, it is important to talk about the limits of hard cutting, such as the machine tools, cutting materials, and other things.[21]

2.22 Philipp G. Grützmacher, ORCID, Francisco J. Profito and Andreas Rosenkranz, ORCID

Surface texturing has been used a lot more in tribological applications in the last 30 years because it has so much promise to reduce wear and friction. Even though biological systems tend to favor hierarchical, multi-scale surface textures, most published experimental and computer studies have focused on the effects of single-scale surface textures. It is likely that not much has been done to use multi-scale surface texture to increase friction and wear. The goal of this review piece is to give an experimental and numerical overview of the state of the art in the field of multi-scale surface textures used in tribological systems. First, a summary of the manufacturing methods used to make multi-scale surface textures is given, along with their pros and cons. Then, the current state of experimental study into the potential and underlying effects of multi-scale textures under dry and lubricated conditions is described. Then, the behavior of multi-scale surface texturing in a lubricated environment is predicted and described using numbers. Lastly, the current knowledge and ideas about the underlying driving mechanisms responsible for the improved tribological performance of multi-scale textures are compiled, and future goals in this field of study are talked about.[22]

2.23 L.M. Vilhena a, M. Sedlaček a, B. Podgornik a, J. Vižintin a, A. Babnik b, J. Možina b

Adding certain textures to a tribological surface can help to cut down on friction in moving contacts. In this study, samples of 100Cr6 steel were treated with a pulsed Nd:YAG laser emitting at 1064 nm to form well-defined surface micro-pores that can be used as lubricant reservoirs, micro-hydrodynamic bearings, and wear debris traps. Because the laser system is very adaptable, it is easy to change the form, size, density, and depth of a structure by changing the laser parameters. Different pulse numbers, different pulse energies, and two different modes (single mode and multi-mode) were used in an experiment to find the best settings for the laser surface texturing process. To describe the micro textures, researchers used optical imaging, scanning electron microscopy (SEM), and topography. Researchers looked at the relationship between the quality and quantity of the micropores and the laser processing factors. Tribological tests were done on laser-textured surfaces using a low-frequency, long-distance, reciprocating slide wear tester with border lubrication. The results were compared to the case where there was no pattern. A tribological study of textured, textured and curved, and untextured surfaces shows that only a small amount of texturing has an effect on the contact conditions under study.[23]

2.24 Meng-Ju Sher,Mark T. WinklerandEric Mazur

We talk about two ways pulsed lasers can be used to make solar devices work better. Pulsed-laser hyperdoping can first introduce dopants into a semiconductor at non-equilibrium concentrations. This forms an intermediate band in the material's bandgap and changes the absorption coefficient. Second, pulsed-laser irradiation can improve geometric light capture by making surfaces rougher. Texturing makes the absorption rate close to one at all wavelengths that can be absorbed. Hyperdoping in silicon makes it possible to capture photons with wavelengths of at least 2.5 m. The effects of each are looked at, along with comments on problems and problems with using each to make solar devices work better.[24]

2.25 G. Ryk,Y. Kligerman &I. Etsion

This study uses experiments to test how well laser texturing can improve the tribological qualities of car parts that move back and forth. Some test results are released with a description of the test setup and the things that were tested. On a simple but representative test sample, friction reduction forecasts based on theory show a good correlation. Also mentioned is a possible benefit of laser surface texturing in cases where there is not enough lubricant. Using cylinder liner segments and piston rings from real production, it has finally been shown that friction can be cut down.[25]

CHAPTER -3 PROBLEM STATEMENT, METHADOLOGY AND EXPERIMENTAL PROCEDURES

Overview

This chapter focus on the goal of the project, the problem we wanted to sort out and the procedure we followed to fabricate this machine.

3.1 PROBLEM STATMENT:

Surface texturing is one of the major topics of research nowadays across the world. There are several techniques, methods and machines that do the surfacing texturing. One of the most vastly used is Laser technique. Laser is the technique with most accuracy and precision and it helps to create the micro patterns at very high precision. The problem occurring is that the laser machine is very expensive. It can't be affordable by all the industries required the surface texturing. Secondly it is not available commercially. In our country Pakistan which is not a very high economical country and economy is decreasing day by day, it is very difficult to find and use the laser technology on small scale or in education sector. Secondly if it is somehow available the cost is so high that it can't be affordable. We must convert this Laser surface texturing machine into a mechanical form so that it could be easily available in market and its price could be as low as possible. These are all the problems that are targeted and will be solved by our surface texturing machine to create the micro patterns. The machine should address the following specific challenges if it is fabricated on industrial level:

1. The machine will be able to create the micro patterns on different surfaces. We used low grade aluminum in our project as a sample material. It will create the micro patterns on the flat surfaces.
2. The machine will help us to make our work more efficient with reducing the time as much as possible.

3. The machine will be easy to operate. Not a very highly qualified worker will be required to operate this machine.
4. This machine and its components will easily be available in the market. It could be manufactured easily and will be available to operate in industries for creating micro patterns.
5. This machine will not be very expensive overall. It should also utilize efficient energy sources and reduce material wastage.

The final deliveries of our project will be:

1. Surface texturing machine that creates micro patterns using indentation on the surface of any soft material.
2. Software control that will help us to control the CNC.
3. User manual for operating the machine.
4. User manual for maintenance of the machine.
5. Recommendation for further improvements in the machine.

3.2 EXPERIMENTAL PROCEDURES:

Before creating this surface texturing machine, we made our research to see what plans do we need to follow to come up with the machine that can fulfil our project goals. It involves several considerations:

1) Define Requirements
2) Research Existing Methods
3) Conceptual Design
4) Mechanism Design
5) Control System
6) Pattern Generation
7) Automation and Software Integration
8) Construct a 3D model
9) Prototype Development
10) Fabrication and Assembly
11) Testing and Calibration

12) Document and Optimization
13) Deployment and Maintenance

3.2.1 Defining Requirements:

Doing the research on the previous work done on this specific type of machines and defining the requirements for surface texturing machine. We highlighted the Factors such as material compatibility, pattern complexity, throughput, desired pattern resolution and automated capabilities.

3.2.2 Researching Existing Methods:

After Studying the machines, methods and research that was already done on this topic. We check and studied the principles and technologies involved, which helped us about the details of design and further innovative ideas. Methods used before were engraving and etching. These were never used for micro patterns instead for other purposes. Other techniques and are

1. Photochemical etching
2. Electrochemical machining
3. Laser machining

3.2.2.1 Photochemical Etching:

In the mid-20th century, the photochemical etching was used for creating the micro patterns. It allows the micro surface texturing but the primary use of the machine was to create the flat two-dimensional patterns. This technique involves the photosensitive materials and selectively remove material from the surface.

3.2.2.2 Electrochemical Machining:

It was developed in 1960s and provided the alternative machining process. It enables the three-dimensional micro patterns. It uses the electric discharge to remove material from the surface. It is usually found in aerospace, automotives and other industries.

3.2.2.3 Laser Machining:

Laser machining was later discovered in late 20th century. It revolutionized the surface texturing to advance levels. It is the most precise and flexible machine for creating micro patterns over a wide and variety of materials. It uses pulse lasers, femtosecond lasers, ultraviolet lasers, which create the high-resolution micro patterns. The only problem is it very costly and not easily available in commercial.

3.2.3 Conceptual Design:

After dealing with the study, we come up with the conceptual design. It includes overall system architecture, components and subsystems required. Factors like motion control, pattern generation mechanisms, tool post and material handling.

We made a rough sketch for this concept

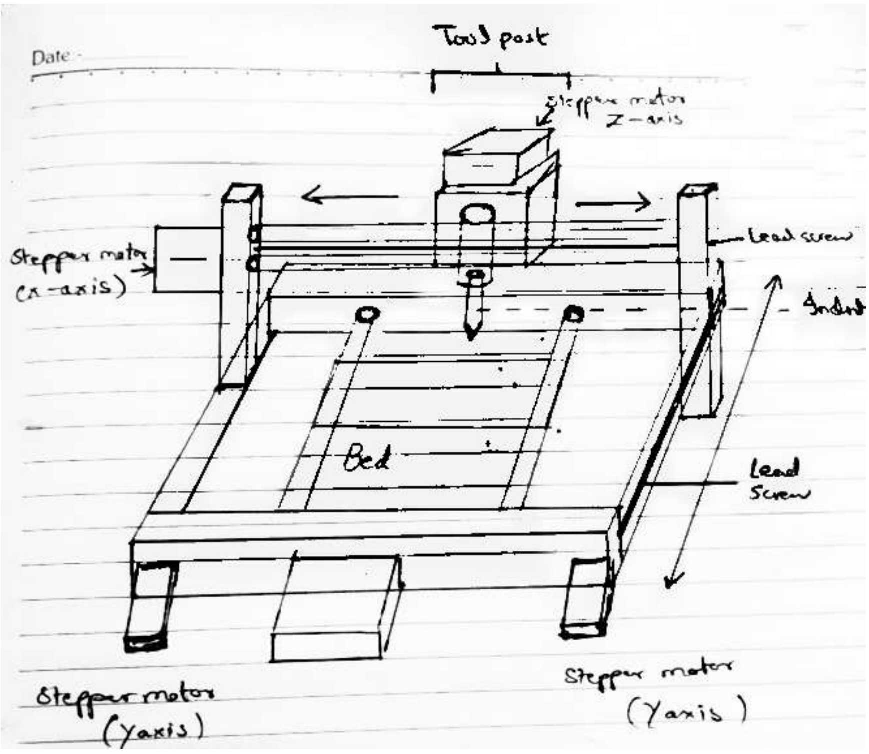


Figure 1: - Concept Design

3.2.4 Mechanism Design:

Firstly, we made sure the design we are making must provide the control over the patterns, stability and rigidity to achieve the desired pattern. We design the mechanical components of the machine such as frame, stages and tool. The CNC is not a new machine, it's been in use for more than a decade but combining an indenting mechanism with CNC is a new thing. The most difficult part was to obtain the required force for indentation. We thought of different mechanisms like using linear force actuator, air compression, hydraulic system but none of these were suitable in our case. Then after giving it a long thought we settled for a normal tool post with a fixed indenter and a high-power motor for the required force and torque.

3.2.5 Control System Design:

We determined the control system of our machine which was the main part for any mechanism including motion control algorithms, sensors, actuators and feedback mechanism. Which we thought will enable precise control over the tool movement and synchronization with pattern generation mechanism. But we didn't fully automate the indenter because it was out of our budget. Our basic requirement was to make a machine that can create micro patterns. So, we used stepper motors for the x and y movement and attached a manual toggle switch for the indenter's movement. All of this was controlled by GRBL.

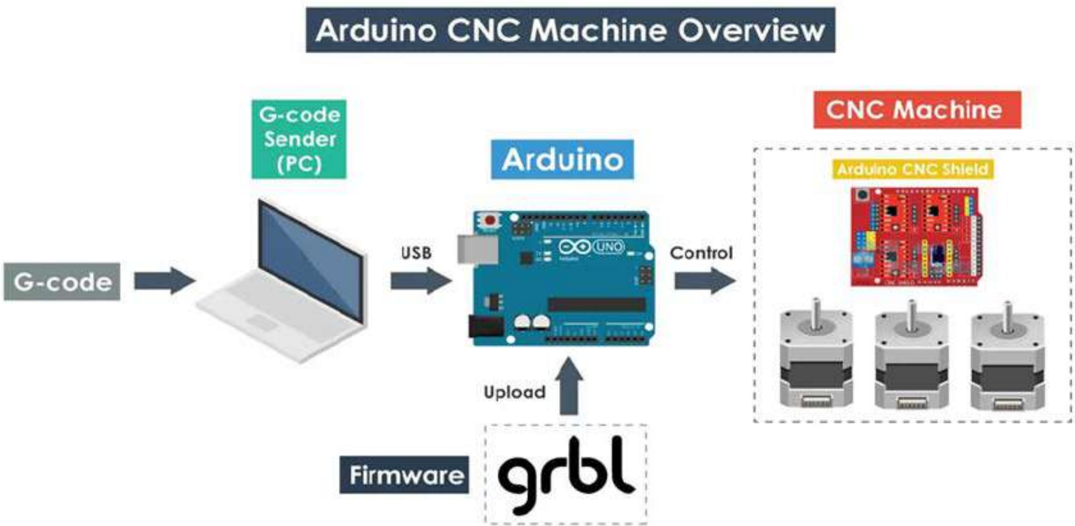


Figure 2: - Control System Overview

3.2.6 Pattern Generation:

Pattern generation was one of the major requirements of the project. The CNC made it easy for us because we just needed a Gcode of the desired pattern, upload it into the machine and operate it. In our testing we used Gcode of a X shape pattern as provided the next page.

3.2.6.1 Gcode:

```
G90       ; Set to absolute positioning mode
G21       ; Set to millimeter units
; Move to the starting position
G0 X0 Y0    ; Rapid move to the starting point
; Set the desired feed rate
F100      ; Set feed rate to 500mm/min
; Move in an X pattern with a delay of 15 seconds after every 10mm
; First quadrant
G1 X10 Y10   ; Move diagonally up to the right
G0 X0 Y0     ; Rapid move to the current position (delay)
G1 X0 Y0     ; Rapid move back to the starting point
; Second quadrant
G1 X-10 Y10  ; Move diagonally down to the left
G0 X0 Y0     ; Rapid move to the current position (delay)
G1 X0 Y0     ; Rapid move back to the starting point
; Third quadrant
G1 X-10 Y-10 ; Move diagonally up to the left
G0 X0 Y0     ; Rapid move to the current position (delay)
G1 X0 Y0     ; Rapid move back to the starting point

; Fourth quadrant
G1 X10 Y-10  ; Move diagonally down to the right
G0 X0 Y0     ; Rapid move to the current position (delay)
G1 X0 Y0     ; Rapid move back to the starting point
```

```
; Return to the starting position
G0 X0 Y0    ; Rapid move to the starting point
M2          ; End of program, stop the machine
```

3.2.7 Automation and Software Integration:

Depending on the requirement we included automation features in the machine to streamline the process. For this we used a software named Universal G Code sender UGS to control the machine x and y movement and handle data input/output. The UGS software serves as a controller for the machine, it has a calibration system so we don’t need to calibrate the machine manually. We can upload a Gcode or write a new one and if we want to operate the machine without Gcode, the Jog Controller can be used.

Figure 3: - UGS Interface

3.2.8 Construction of a 3D Model:

We then started working on the construction of CAD model for the machine on solid works and Fusion 360 and were satisfied with this design:

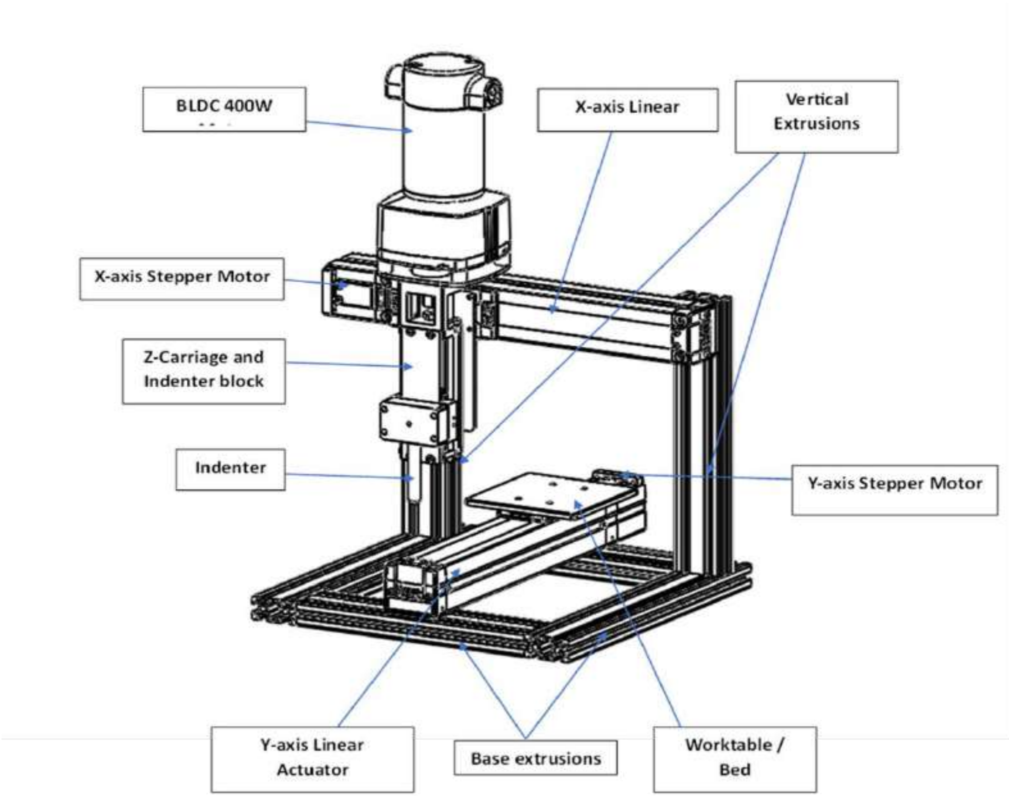


Figure 4: - Labeled CAD Model

After this we did the complete analysis on it. It helped us visualize the idea that we put so much thought into. The 3D model helped us list down the required components and in market survey.

3.2.9 Fabrication and Assembly:

Once the testing on the CAD model was complete, we moved towards the actual machine. Proceeding with the fabrication and ensuring the proper assembly and integration of all subsystems, adhering to safety standards and regulations.

3.2.10 Testing and Calibration:

After completing the fabrication, we tested our machine comprehensively to verify its operation. Performed different test with different material for the optimal performance.

3.2.11 Documentation and Optimization:

We will document the design, fabrication process, operational manual and operational procedures for future reference. Identify areas for improvement and optimization.

It is important for us to note that design and fabrication is all depended upon the work, material and specific output required. Fabricating the surface texturing machine that can create micro patterns through indentation was our top priority. Consulting the experts, after studying a lot of research papers, doing a lot of testing and calibrations we finally achieved our goal.

3.2.12 Maintenance:

It is necessary to establish a schedule for the maintenance to ensure the machine's longevity and optimal performance. The maintenance of this machine is quite easy and cheap. If only these four things are kept in check, then the machine will work just fine.

1. Regular Cleaning
2. Lubrication
3. Calibration
4. Inspection before use

CHAPTER -4 MACHINE COMPONENTS AND CAD MODEL

Overview

This chapter includes the design details of the machine along with components specs. The first part is based on CAD Model and contains the design sheets of major components from SOLIDWORKS software. The second part of the chapter contains the basic detail of the components used in the machine.

4.1 CAD Model:

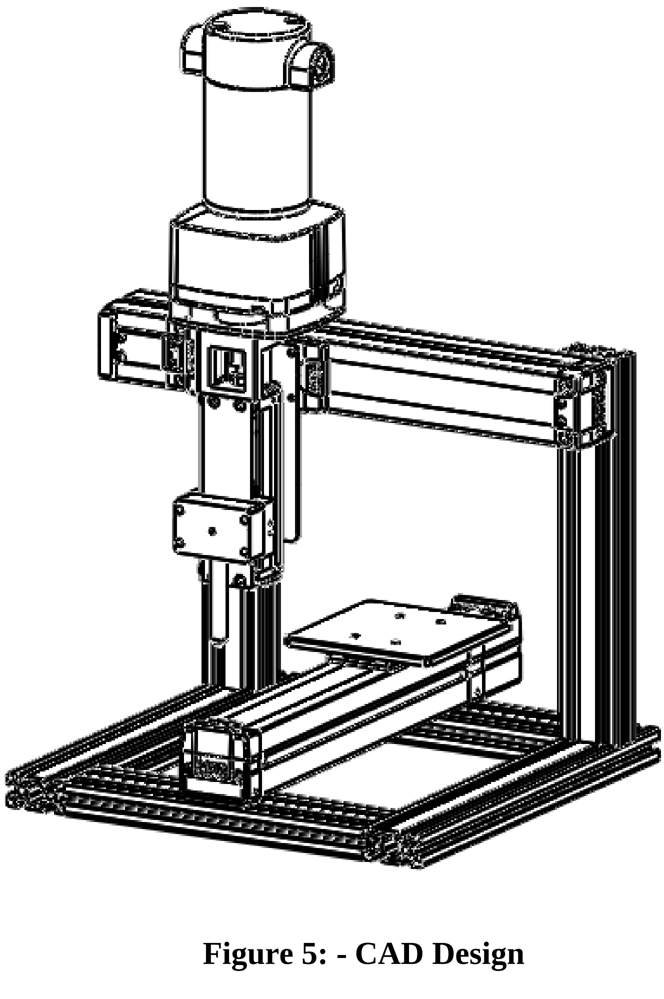


Figure 5: - CAD Design

4.1.1 Frame:

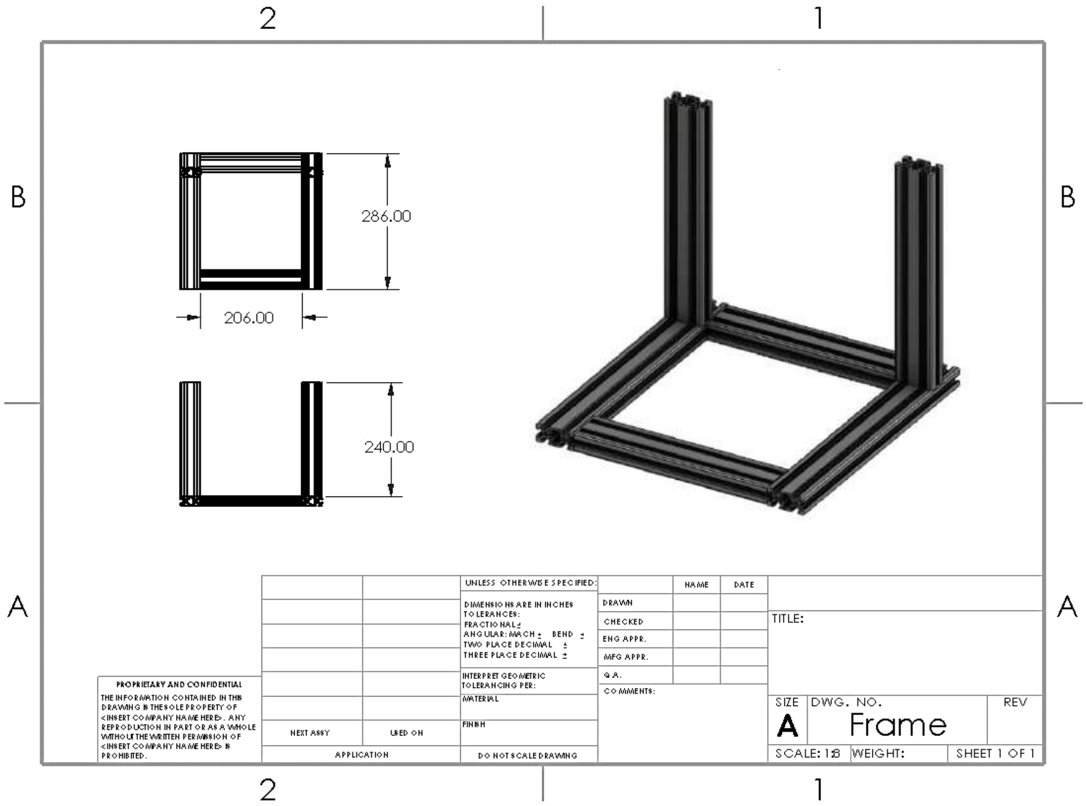


Figure 6: - Frame Design

4.1.2Actuators:

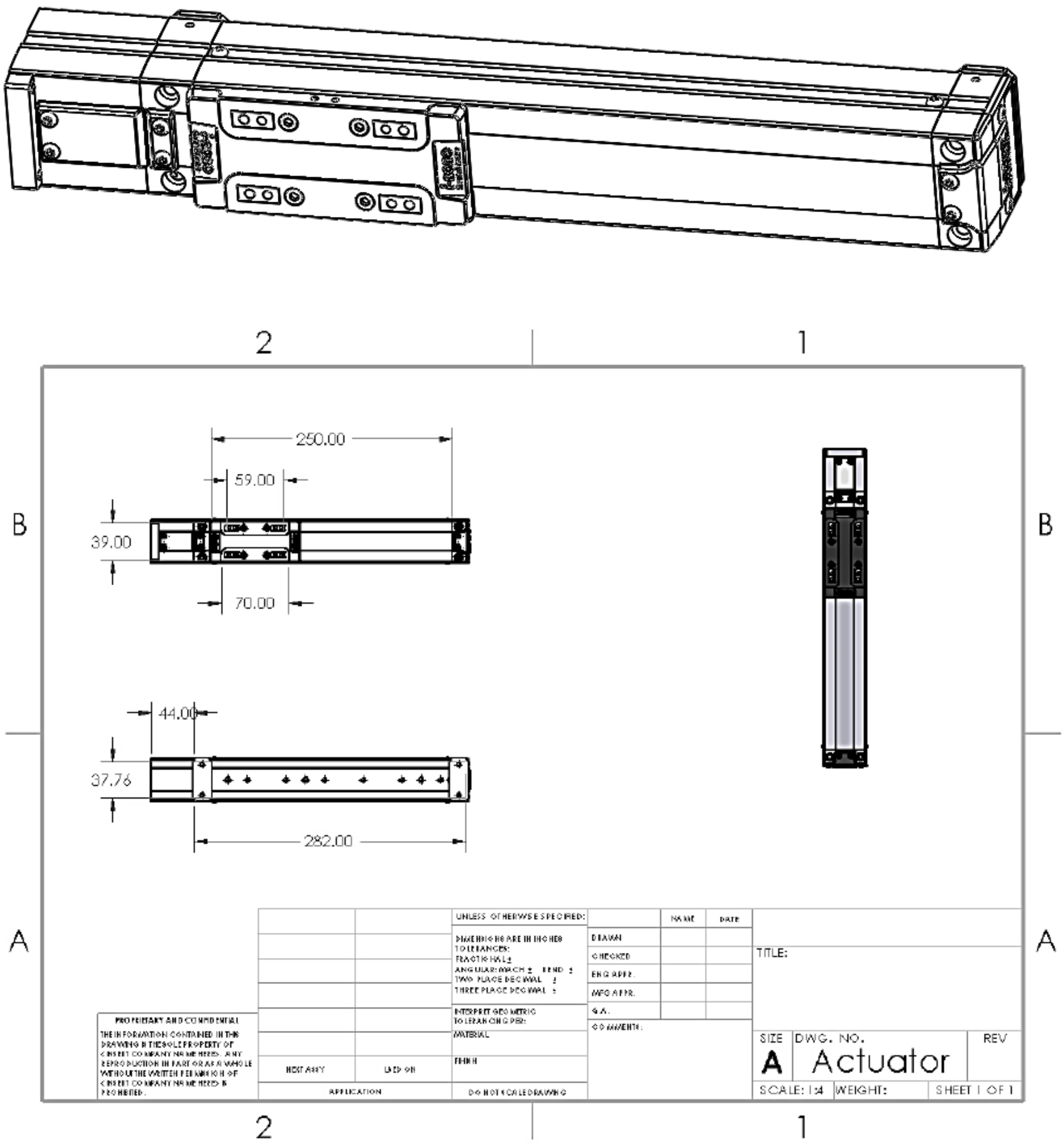
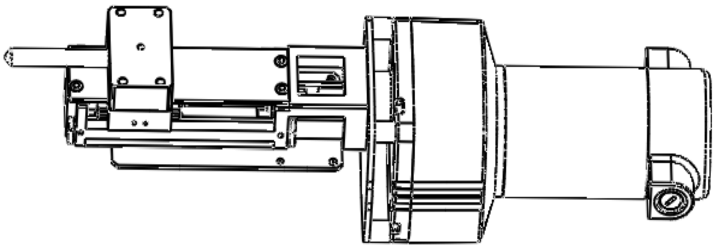


Figure 7: - Linear Actuator Design

4.1.3 Z Carriage:



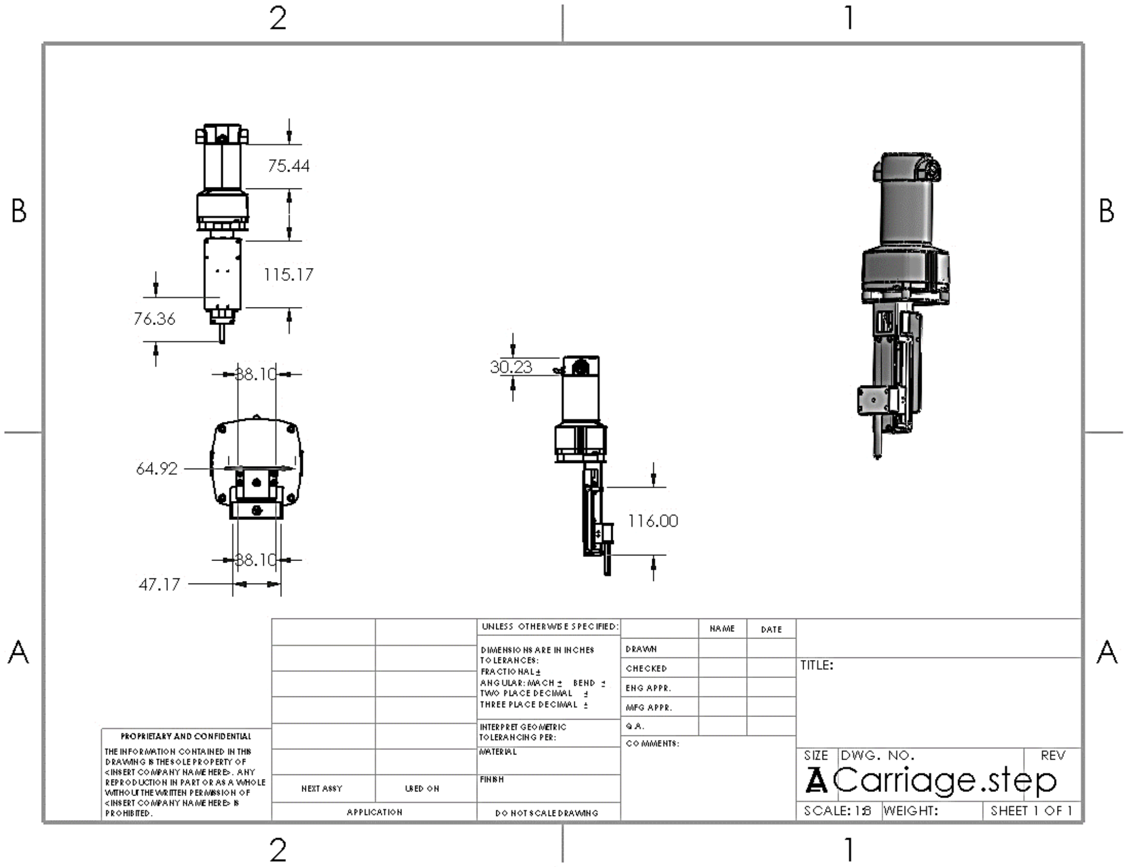


Figure 8: - Z Carriage Design

4.1.4 Work Area / Bed:

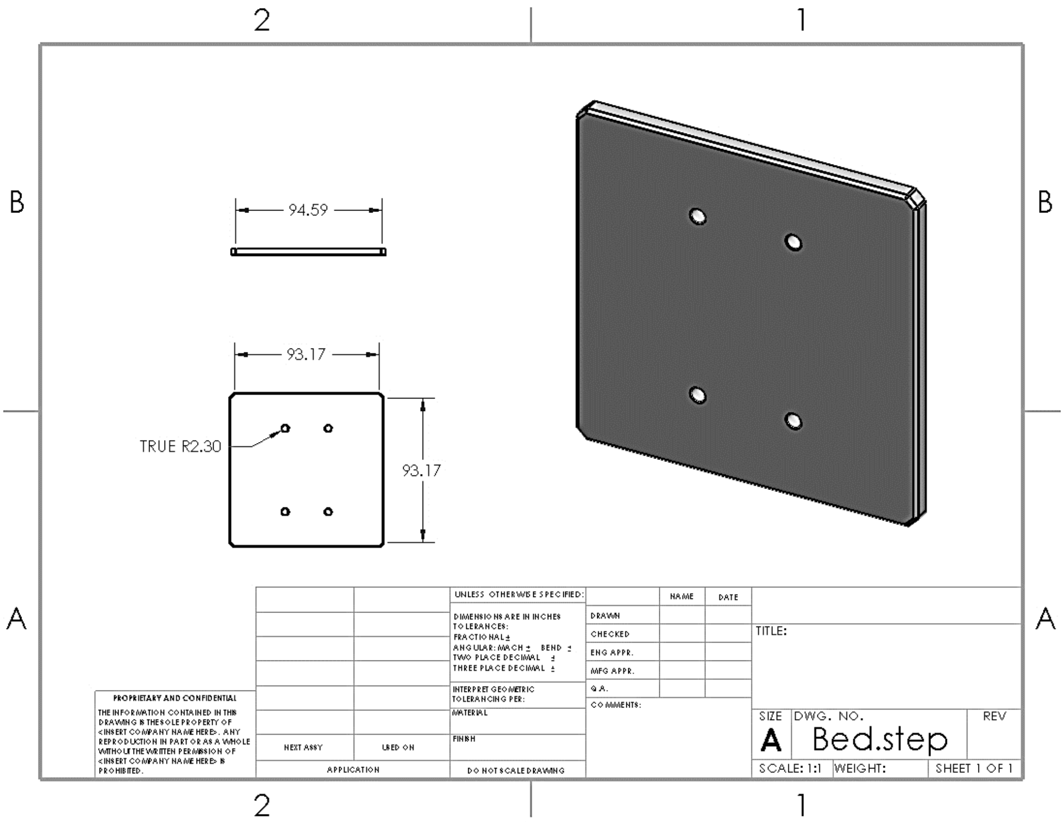


Figure 9: - Work Area or Bed Design

4.1.5 Renders

Figure 10: - Isometric view

Figure 11: - Front view

Figure 12: - Side view

4.2 Key Components:

The machine consists of several key components. Understanding the machine's components and construction will help the readers understand the working of the machine.

4.2.1 Aluminum Profile (AA 6063)

AA 6063 is an aluminum alloy that is commonly used for extrusion profiles, including those used in CNC machines. In this machine 6 profiles are used for Machine’s Frames with Thickness of 2mm & lengths:

Lx = 206mm   Ly = 286mm   Lz = 240mm

Light weight   High Strength   Machinability

Corrosion Resistance

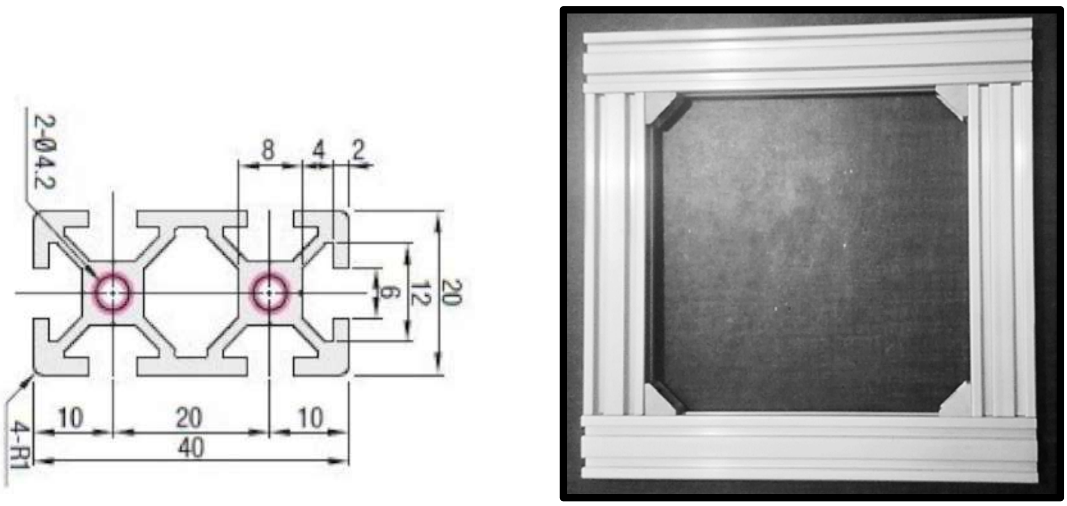


Figure 13: - Aluminum Extrusions

4.2.2 Indenter:

The indenter serves as the pivotal component in this machine, as it is responsible for creating the desired indent on the workpiece. To ensure optimal performance and durability, we have incorporated a custom-fabricated indenter

Rod Length: 79mm & radius: 4.064 mm

Tip size: 4mm

Material: Stainless Steel

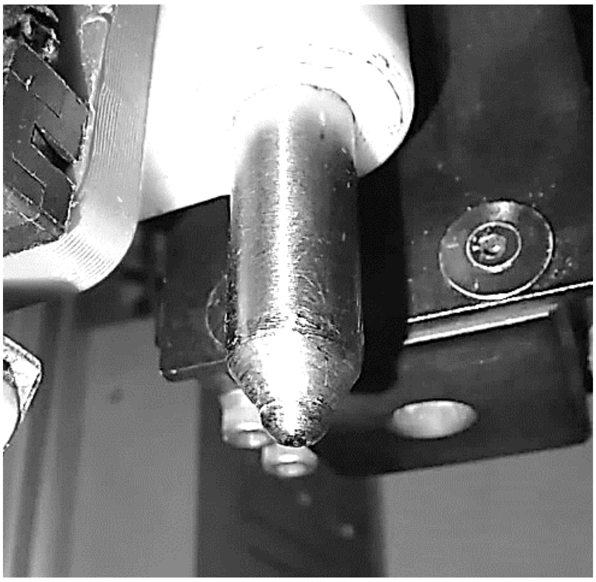


Figure 14: - Indenter

4.2.3 Stepper Motors

A stepper motor, also known as step motor or stepping motor, is a brushless DC electric motor that divides a full rotation into a number of equal steps.

Two phase NEMA 17 stepper motors are used for X and Y movement.

Specifications:

Rated Voltage:	12V DC
Current:	1.2A at 4V
Step Angle:	1.8 deg.
No. of Phases:	2 & 5
Motor Length:	1.54 inches
Operating Temperature:	-10 to 40 °C
Unipolar Holding Torque:	22.2 oz-in

4-wire, 8 inch lead

200 steps per revolution, 1.8 degrees

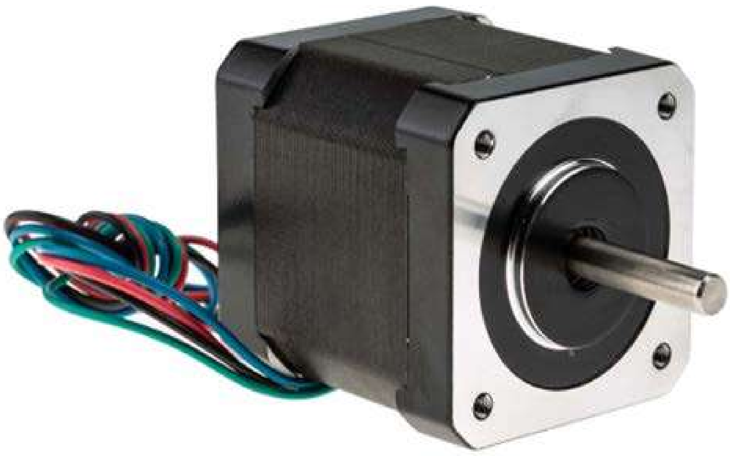


Figure 15: - Stepper Motor

4.2.4 BLDC Motor:

To provide the required force of 400N for indentation. We are using a BLDC Motor of 400W of BODINE ELECTRIC COMPANY with specs such as

RPM:	80 to 100 (approx.)	Rated Torque:	26.8 Nm
Rated Voltage:	24V	Amps:	18
Peak Torque:	33 to 35 Nm (Approx.)	Motor HP:	½ Gear Ratio: 30

Figure 16: - BLDC Motor

4.2.5 Bed:

A CNC machine bed refers to the flat and rigid surface on which the workpiece is securely placed and fixed during the indentation process.

Material: Stainless Steel (Heat Treatment)

Area: 9525.87mm Thickness: 4mm

Figure 17: - Work area or bed

4.2.6 Actuator:

Linear actuators are devices that convert rotational motion into linear motion, and provides controlled movement in a straight line.

We used **SAN4505ER-150S** Smart Actuator by i-ROBO

- High rigidity and compact design.
- Ball Screw Driven
- Easy-various motors attachment
- 2000mm maximum standard stroke.
- High positioning repeatability ±5㎛
- Stainless steel cover design.
- Environment-friendly system

Figure 18: - Actuators

Table 4.2.6.1 Actuators Specs 1

Model	Width	Screw Lead (mm)	Ball Screw	Max Load (kg) (X)	Max Load (kg) (Y)	Max Load (kg) (Z)	Stroke (mm)
SAN45	 45 mm	5	Ø12 (Precision rolling)	13	8	4	50 ~ 500
		10		12	7	3.5	
		20	Ø12 (Grinding C7)	5	4	2.5	
SAN45H		5	Ø12 (Precision rolling)	16	10	5	50 ~ 500
		10		15	9	4	
		20	Ø12 (Grinding C7)	6	5	3	

4.2.7 Controller:

We have an Arduino-based controller setup with a CNC shield, and we are using Universal Gcode Sender (UGS) as our control software. The whole control unit is powered by **FES600-24 Supply**. We are only controlling x and y Stepper motors through Controller.

For Z-Carriage, a separate toggle switch is installed to manually move the Indenter.

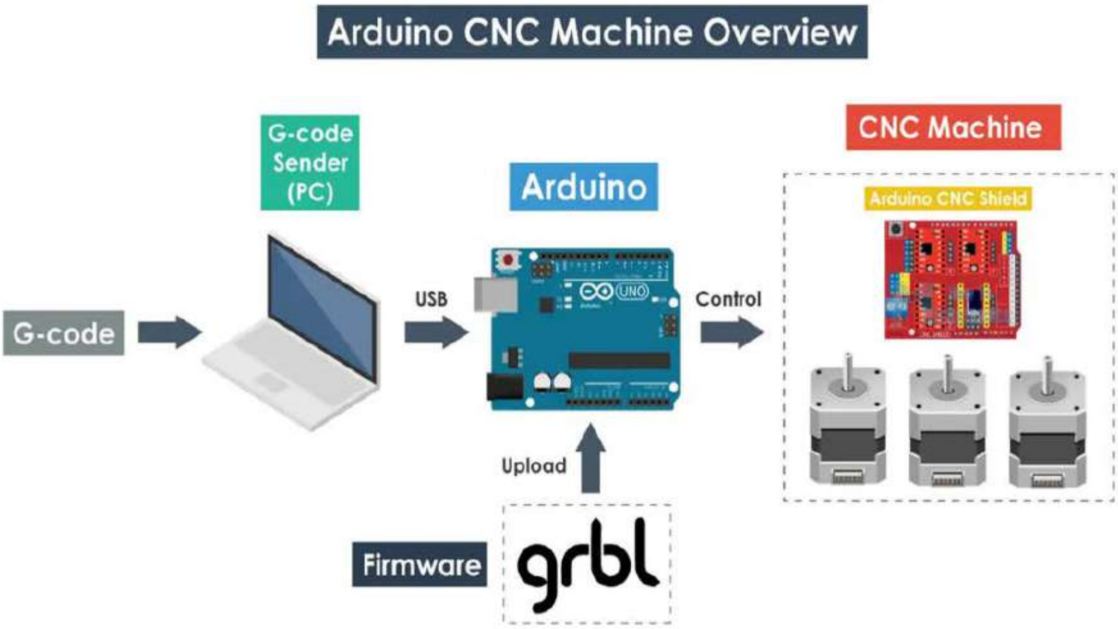


Figure 19: - GBRL Overview

4.2.8 Power Supply:

The **FLS600-24** power supply by **FINE** is a 24V (600W) power supply commonly used in various applications, including CNC machines. It provides a stable and reliable power source for the components of the CNC system.

- Resonant Converter
- Forced Air Cooling
- Input Voltage (AC IN 187V – 264V)
- Built-in Inrush System
- Protections: Short Circuit/Overload
  - Over Voltage/Over Temperature

Figure 20: - Power Supply

Table 4.2.8.1 Power supply specs 1

MODEL	FLS 600-05	FLS 600-12	FLS 600-15	FLS 600-24	FLS 600-48
OUTPUT VOLTAGE (V)	5	12	15	24	48
OUTPUT CURRENT (A)	120	50	40	25	12.5

4.2.9 Toggle & Stop Switch:

We are only controlling x and y Stepper motors through Controller. For Z-Carriage, a separate toggle switch is installed to manually move the Indenter.

1. When toggled upward, the indenter moves up.
2. When toggled down, indenter moves down.

When desired indent depth is reached, the limit switch cut off the power from the main supply results in stopping the indenter from going any further.

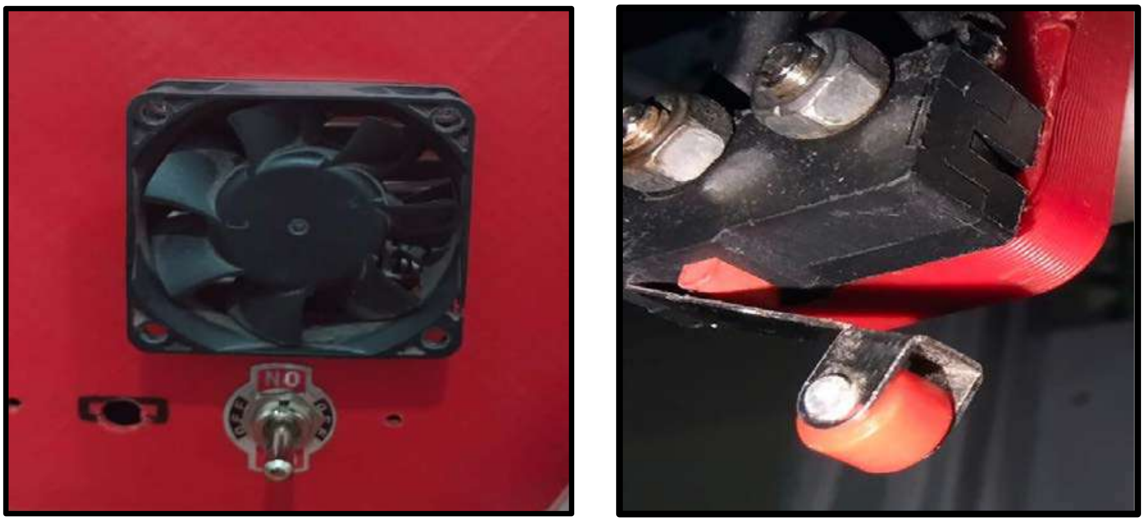


Figure 21: - Toggle Switch and Stop Switch

CHAPTER-5 CALCULATIONS AND RESULTS

Overview

This chapter is focused on the necessary calculations used in this project and final results. This project was choice based so we only needed the required indentation force to design this machine and fulfil the requirements. The theoretical force for Aluminum workpiece is calculated as:

5.1 Force Calculation

We calculated an approximate value for the force of indentation using the simple formula

F = PA

Given:

Radius of indenter tip = 2mm

P= 30MPa (Yield Point)

Contact Area:

A = pi*r^2

A = 3.14*(2*10^-3m) ^2

A = 1.258*10^-5m^2

Simulations Results on Indenter & Bed (Stainless Steel) with 65KG applied load in Fusion 360.

Verification of the Fusion 360 Analysis:

Verifying the fusion 360 analysis of 65Kg point load on stainless steel bed through reverse engineering method, using the resultant contact pressure 49.83MPa.

P = F/A

Substituting the values:

49.83 MPa = F /(1.258*10^-5m^2)

F = 49.83*10^6 Pa * (1.258*10^-5m^2)

F = 622.875 N ≈ 63.5 Kg (verified)

5.2 Analysis Results

After running simulations in FUSION360 we got following results.

Max Stress: 45.12 MPa

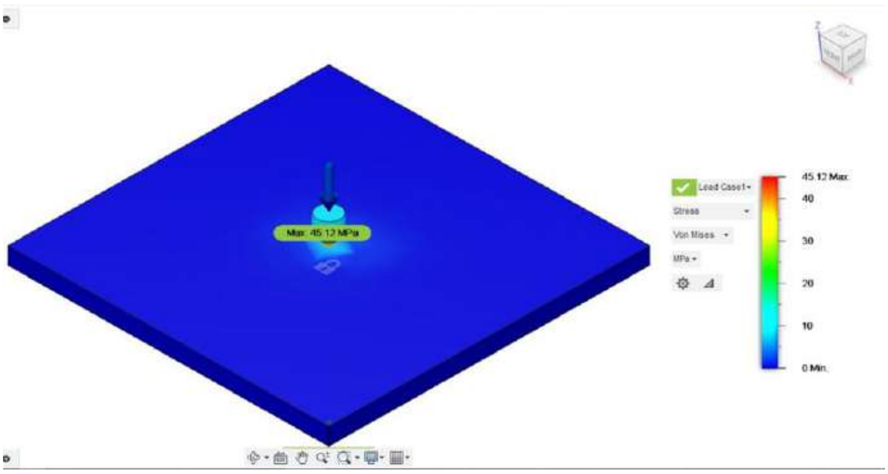


Figure 22: - Max Stress

Contact Pressure: 49.83 MPa

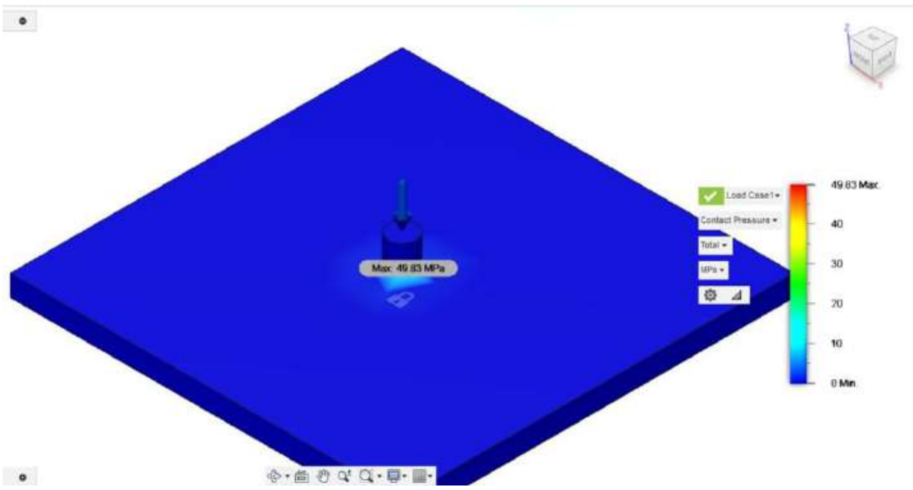


Figure 23: - Contact Pressure

Max Strain: 2.296E-04

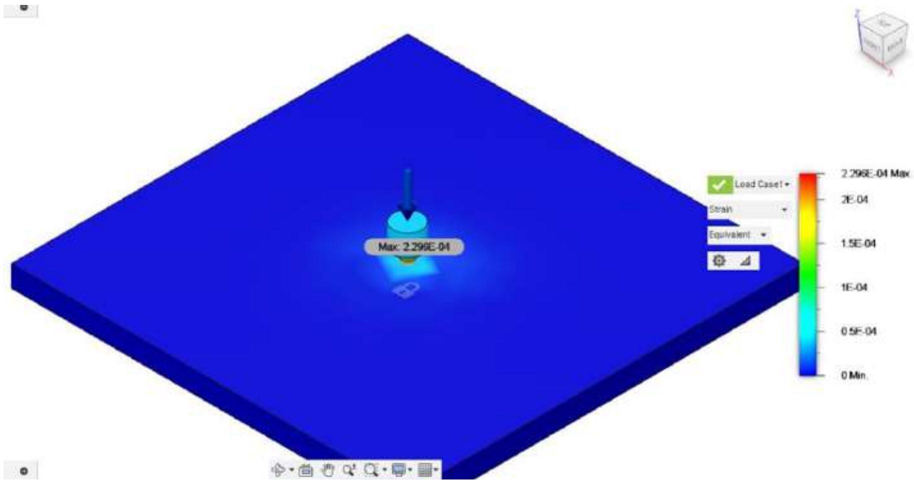


Figure 24: - Max Strain

Safety Factor: 4.5

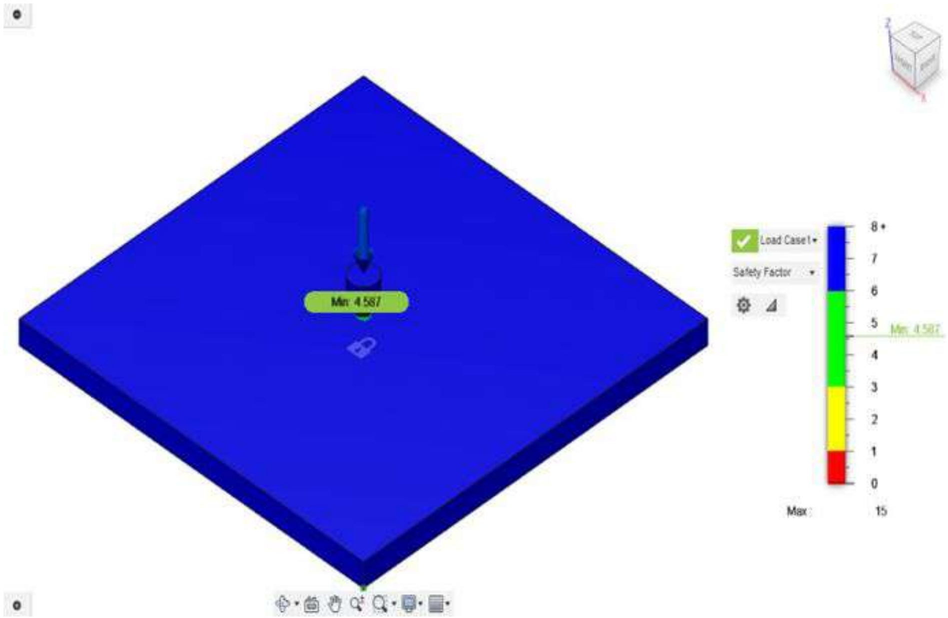


Figure 24: - Factor of Safety

5.3 Torque Calculation

The minimum torque required for the indentation in soft Aluminum is

$$T = F*r$$

Where,

F is the Force & r is the distance between lever arm and the bed

Keeping the r minimum as 10 mm = 0.01m

Substituting the values:

$$T = 376N * 0.01m$$

$$T = 3.768\ Nm$$ (that lies within the specs of the motor)

5.4 Pattern Results

Figure 25: - Macro Indents

Figure 26: - Micro Indents

CHAPTER-6 BUDGETING AND COSTING OF THE PROJECT

Overview

This chapter includes the budgeting and costing of the project. It includes the cost we estimated at the start of the project to the actual cost spent on the project including transportation, manufacturing and other expenses.

6.1 Budgeting of the Project

This chapter includes the budgeting and costing of the project. It includes the cost we estimated at the start of the project to the actual cost spent on the project including transportation, manufacturing and other expenses.

6.1.1 Estimated Cost of The Project

In the start of the project the estimated cost was based on the price of the major components of the machine. The manufacturing cost was estimated according to the market rate at that time. Miscellaneous cost is not included.

Sr. No	Particulars	Qty	Base Price (PKR)
1	Nema motors	2	5000
2	400W BLDC Motor	1	10000
3	Arduino Uno	1	2000
4	CNC Sheild	1	600
5	Actuators	1	40000
6	Couplings	1	2500

7	6063 Frame	1	6000
8	4mm Aluminum Fixture Plate	2	1780
9	100x100mm Bed Plate	1	2100
10	Z Axis Carriage	1	2600
11	Indenter	1	2000
12	Manufacturing cost		10000
13	Transportation cost		10000
14	Electrical wires		1000
15	Coding		5000
16	M4x8	8	80
17	M4x45	8	280
18	M4 T-Slot Nut	16	720
19	M5 T-Slot Nut	10	450
20	M5x10	10	120
Total			102,230

Table 6.1.1.1: - Estimated Cost 1

6.1.2 Actual Cost of The Project

The actual cost of the project includes the price table according to the current market rate and the price at which we procured the material.

Sr. No	Particulars	Qty	Base Price (PKR)
Electronics			
1	X Nema 17	1	3800
2	Y Nema 17	1	3600
3	400W BLDC Motor	1	18000
4	Gearbox 30 Reduction	1	6500
5	Arduino Uno	1	2200
6	CNC Sheild	1	650
7	A4988 Drivers	2	740
8	60x60 Fan	1	130
9	Wiring Harness	1	1400
10	24v 650W PSU	1	8900
11	LED Switch	1	650
12	Miscellaneous		1200
Total			47770
Linear Actuators			
1	X-Actuator	1	26500

2	Y-Actuator	1	27200
3	Z-Actuator	1	14800
4	X-Flexible Couplings	1	1150
5	Y-Flexible Couplings	1	1200
6	Z-Rigid Couplings	1	1600
Total			72450
Frame			
1	6063 Frame	1	8900
2	2020 Corner Cube	4	720
3	4mm Aluminum Fixture Plate	2	1780
4	100x100mm Bed Plate	1	2100
5	Z Axis Carriage	1	2600
6	Indenting Mechanism	1	3800
Total			19900
3D Printed Parts			
1	Motherboard Housing	1	4000
2	Housing Cover	1	800
3	PSU Cover	1	1500
4	Covers	1	1500

Total			7800
Fasteners			
1	M4x8	8	80
2	M4x45	8	280
3	M4 T-Slot Nut	16	720
4	M5 T-Slot Nut	10	450
5	M5x10	10	120
6	Miscellaneous		550
Total			2200
Grand Total			150120

Table 6.1.2.1: - Actual Cost 1

6.2 Costing of The Project

The costing includes expanding the allocated money. The direct and indirect expenditures are included in the project, direct costs are traced and indirect costs are allocated.

6.2.1 Direct expenses

These expenses can be directly traced back to the project.

Sr. No	Particulars	Qty	Base Price (PKR)
Electronics			
1	X Nema 17	1	3800
2	Y Nema 17	1	3600

3	400W BLDC Motor	1	18000
4	Gearbox 30 Reduction	1	6500
5	Arduino Uno	1	2200
6	CNC Sheild	1	650
7	A4988 Drivers	2	740
8	60x60 Fan	1	130
9	Wiring Harness	1	1400
10	24v 650W PSU	1	8900
11	LED Switch	1	650
12	Miscellaneous		1200
Total			47770
Linear Actuators			
1	X-Actuator	1	26500
2	Y-Actuator	1	27200
3	Z-Actuator	1	14800
4	X-Flexible Couplings	1	1150
5	Y-Flexible Couplings	1	1200
6	Z-Rigid Couplings	1	1600
Total			72450

Frame			
1	6063 Frame	1	8900
2	2020 Corner Cube	4	720
3	4mm Aluminum Fixture Plate	2	1780
4	100x100mm Bed Plate	1	2100
5	Z Axis Carriage	1	2600
6	Indenting Mechanism	1	3800
Total			19900
3D Printed Parts			
1	Motherboard Housing	1	4000
2	Housing Cover	1	800
3	PSU Cover	1	1500
4	Covers	1	1500
Total			7800
Fasteners			
1	M4x8	8	80
2	M4x45	8	280
3	M4 T-Slot Nut	16	720
4	M5 T-Slot Nut	10	450

5	M5x10	10	120
6	Miscellaneous		550
Total			2200
Grand Total			150120

Table 6.2.1.1: - Direct Expense 1

6.2.2 Indirect expenses

These expenses are not directly traced back to the product but this cost is necessary for the project.

Others		
1	Transportation	15000
2	Manufacturing	10000
3	Documentation	7000
4	Tools	1500
5	Rents	5000
Total		38500

Table 6.2.2.1: - Indirect Expenses 1

CHAPTER-7 CONCLUSION

Overview:

In this chapter, we outlined the success of our project in comparison to the objectives we selected at the beginning. Important findings are summarized and the utility of the project is highlighted. The impact likely to be made by the project if adopted in an industry or in routine life is focused.

7.1 Performance Review:

During this project, our CNC indentation machine did a great job of making micro-dents in Aluminum and other light materials. The smooth operation of the x and y steppers through UGS and the effective use of a BLDC motor on the z-axis made the indentation process go smoothly. By adding a manual control system with a toggle switch, the machine became even more flexible and easy to use.

Even with this success, we came across a major issue when we tried to use the machine on high-quality materials (Stainless Steel). The indenter's tendency to slip and scratch the surface was a difficult problem to solve. After a lot of research, it seems that the way machine is designed now may not be the best way to handle the unique features of high-grade materials. To fix this problem, more research needs to be done on material-specific factors and possible improvements in frame design and components.

7.2 Overall Conclusion:

The success of designing and making our CNC indentation machine can prove to be a big step forward in the field of surface texturing. The fact that this machine can make micro-dents on aluminum and other light materials shows that it could be helpful in a lot of ways.

Even though the CNC indentation machine did not work as well as expected on high-quality materials, it is still a good base for future research and improvement. We have learned a lot about mechanical engineering and how it works in the real world thanks to the valuable experience we gained from this project.

We know how important it is to know your limits and find ways to improve. As people who want to pursue careers as mechanical engineers, we are still committed to improving this new machine, pushing the limits of mechanical engineering, and helping the field move forward.

In the end, this project showed us how important it is to work as a team and think critically about problems. We are very grateful to everyone who helped us and showed us the way on this journey. As we move forward, we hope that our work will spur more study and new ideas, leading to the creation of more advanced CNC indentation machines that can be used in a wider range of industries.

CHAPTER-8 FUTURE PROSPECTS AND RECOMMENDATIONS

Overview:

In this chapter, we recommend improvements in the project to be taken as a separate work, which we were not able to do in view of time and financial constraints.

8.1 Recommendations:

Even though we achieved our objectives for this project but there is still room for improvement before this machine can be built on industrial scale.

8.1.1 Material and Geometry of the Indenter:

Conduct research on a variety of indenter materials and geometries to determine which design is the most appropriate for each particular type of material. Customizing the design of the indenter can reduce the amount of scratching and slippage that occurs, resulting in improved indentation results on a wider variety of materials.

8.1.2 Automation of Z Carriage:

The Z carriage is left manual because of time and budget constraints. But it can be automated for more precision and control. Normal CNC Shield with Arduino cannot control two steppers and one 400W BLDC Motor. So for this purpose, we will recommend using strain gauges with indenter, E4 board or NVBD Board.

8.1.2.1 FYSETC E4 Board

Use of FYSETC E4 Board with Built-In Wi-Fi and Bluetooth 4 Pcs TMC2209 240MHz 16M Flash 3D Printer Control Board Based For 3D Printer and CNC.

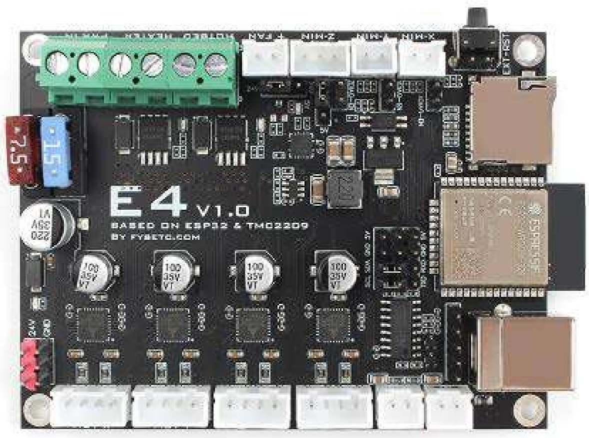


Figure 27: - FYSETC E4 Board

8.1.2.2 NVBD:

A brushless DC (BLDC) motor driver controller is a piece of hardware that regulates the speed and direction of a brushless DC motor. It typically comprises of a power amplifier that drives the motor and a control circuit that reads feedback from the motor and adjusts the power amplifier accordingly.

Figure 28: - NVBDH+ Brushless Motor Driver with Hall

8.1.3 Feedback Loop Control:

For continuous monitoring of the indentation process, incorporate real-time feedback systems into the machine. It is possible for closed-loop control systems to automatically alter indentation parameters in response to feedback, which ensures accurate and consistent results.

8.2 Future Prospects:

This project has opened up interesting new ways to look at the future of material texturing and indentation technology, as well as possible ways to make it better. Even though it has some problems now, we think that with more study and development, this machine can become a very useful and important tool. Here are some important things to look forward to with the CNC indentation machine:

8.2.1 Improved Material Compatibility:

Fixing the problem of the indenter slipping on high-grade materials is still a big place for improvement. We can make the machine work with a wider range of materials, such as high-strength alloys and advanced composites, by studying the material-specific factors and changing the design and control methods accordingly.

8.2.2 Material Science & Research:

This machine can prove to be an important tool for material science and research because with a little more work and improvements it can give researchers important information about the properties, strength, and deformation of a material. It can help scientists study the mechanical qualities of new materials, composites, and coatings, with minimum cost, which can lead to improvements in the field of materials science.

8.2.3 Quality Control and Manufacturing:

The machine can be used for quality control during the manufacturing process in fields like aerospace, auto, and electronics. The ability to do micro-indentation on lightweight parts makes sure that the quality and reliability of the result is always the same.

8.2.4 Nanotechnology Research:

This machine can help with nanotechnology research and the study of nanomaterials if its design is changed a little bit for nano indentation. To move nanotechnology uses forward, it is important to understand the mechanical properties at the nanoscale.

8.2.5 Thin Films and Coatings:

This machine can help the semiconductor and thin-film businesses evaluate the hardness and adhesion properties of coatings to make them last longer and work better.

8.2.6 Failure Analysis and Forensics:

This machine can help with material failure investigations and failure analysis. By looking at the indentation patterns on broken parts, engineers can figure out the failure reason and it can also be deployed for fatigue tests if improved up to the industrial scale.

The direction that things will move in the future is always toward making life easier for people and bringing in more money. This feature is available on this machine, which is advantageous from a financial standpoint as well as from a learning and research one.

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