Sudan University of Science and Technology
College of Graduate Studies

Design and Development of an Automated Metal Inert Gas/ Metal Active Gas Welding Machine

تصميم وتطوير ماكينة اتوماتيكية للحام بالقوس المعدني والغاز الخامل و اللحام بالقوس المعدني والغاز النشط

A thesis Submitted in Partial Fulfillment of the Requirement for the Degree of M.Sc. in Mechatronics Engineering

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الإستهلال

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

وَٱصْبِرْ نَفْسَكَ مَعَ ٱلَّذِينَ يَدْعُونَ رَبَّهُم بِٱلْغَدَوٰةِ وَٱلْعَشِيِّ يُرِيدُونَ وَجْهَهُۥ وَلَا تَعْدُ عَيْنَاكَ عَنْهُمْ تُرِيدُ زِينَةَ ٱلْحَيَوٰةِ
ٱلدُّنْيَا وَلَا تُطِعْ مَنْ أَغْفَلْنَا قَلْبَهُۥ عَن ذِكْرِنَا وَٱتَّبَعَ هَوَىٰهُ وَكَانَ أَمْرُهُۥ فُرُطًا ﴿٢٨﴾

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Foremost, I would like to express my sincere gratitude to my advisor Dr. Ebtihal Haidar Gismalla for the continuous support of my Master thesis study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my Master thesis study.

Abstract

Automated welding is the most preferred welding technique when it comes to construction of welding sheet metal of various thickness.The MAG welding machine has a relay switch to control ON/OFF operation of welding torch. The essential feature of the process is the small diameter electrode wire, which is fed continuously into the arc from a roller of wire which installed on welding machine . The base metal used for welding is carbon steel.

The Methodology which was used prior to the automated system included Welding which was done by means of hand held Welding guns. This method had less accuracy and precision as compared to the automated system of welding. The process consumes more operating time and it requires large no of workers for production as increase in man power directly effects on production rate and production cost as well as profit margin. Also, the production processes like welding technique which was implemented had safety issues. The automated method was proposed to getting high welding quality and accuracy ,in addition increase the productivity of welding and safety worker. Through this project, the focus is to completely eliminate human contact during welding which will no doubt be safer but will also be more efficient. The machine is used to weld work pieces in flat position since higher deposition rates are achieved in this position and is a convenient approach. The machine system will be able to implemented any contour in 2D profile that is generated over a program user interface (CAD). Electronic devices such as stepper motors and driver board are interfaced with break out board. The break out board PMDX-122-1200 is used to signal the stepper motors to rotate while deciphering the G-code.

In this project, the emphasis is given on design calculation and structural analysis. the design model implemented by using solid work software and analyzed the design by using ansys software. Setup makes use of four stepper motors of 5.4 N.m capacity for efficient movements in three axes.

After fabrication and testing for Automatic welding machine for small scale to large scale industries are optimized the cost. In addition to that the quality of the weld is also quite paramount therefore using an technique for automatic welding and Industrial implementation of Automation improves productivity as well as profit margin per component. This project efficiently helps to fully automate the process of Welding. The project will provides the practical description of the components implemented in the control system along with the flow of working of various components.

المستخلص

يعتبر اللحام الآلي الاكثر تفضيلا عندما يتعلق الامر بلحام السماكات المختلفة من الصاج حيث يسمح اللحام الالي بإنشاء والحفاظ علي وصلة اللحام بجودة عالية، مما يضمن الكفاءة العالية والمرونة والانتاجية العالية. تعتمد ماكينة اللحام بالقوس المعدني والغاز النشط الالية علي مفتاح تشغيل واغلاق لكاوية اللحام لاشعال القوس الكهربائي لبدء عملية اللحام . السمة الأساسية لهذه العملية هي سلك اللحام الصغير ، والذي يتم تغذيته باستمرار في القوس الكهربائي من خلال بكرة السلك الموجودة في ماكينة اللحام . من المعادن الأساسية المستخدمة لهذا النوع من اللحام هو الكربون الصلب.

الطريقة المستخدمة قبل النظام الآلي هي الطريقة اليدوية التي يستخدم فيها مسدس اللحام يدويا. تعتبر هذه الطريقة اقل دقة وكفاءة مقارنة بالنظام الآلي، هذه العملية تستهلك أيضا وقتا أطول للتشغيل كما انها تحتاج الي عدد اكبر من العاملين للإنتاج، حيث تؤثر زيادة القوي الإنتاجية علي معدل الإنتاج والتكلفة بصورة مباشرة، كما أن هنالك بعض المشاكل المتعلقة بالسلامة في العمليات الإنتاجية اليدوية. لذلك تم اقتراح الطريقة الاتوماتكية للحام للحصول علي جودة ودقة في اللحام بالإضافة لزيادة الإنتاجية وسلامة العاملين. من خلال هذا المشروع ، يتم التركيز على القضاء التام على التدخل اليدوي في عملية اللحام والذي سيكون بلا شك أكثر أمانا كما أنه سيكون أيضا أكثر كفاءة.

يتم استخدام الماكينة لعمليات اللحام السطحية الوضع التي يكون فيها معدل الأنصهار عالي وهي طريقة ملائمة جدا. نظام الماكينة قادر علي تنفيذ اي كنتور في ملف ثنائي الأبعاد(٢D) يتم أنشاؤه من خلال واجهة مستخدم برنامج ال (كاد). الأجهزة الإلكترونية مثل محركات الدوران و والمتحكمات ترتبط بلوحة التحكم الرئيسة (برك ات برد). لوحة التحكم الرئيسة من نوع PMDX١٢٢١٢٠٠ تستخدم لنقل إشارة حركة المحركات أثناء عملية فك شفرة الكود (لDوCي). تم تنفيد التصميم بواسطة برنامج سوليد ويرك وتم التحليل بواسطة برنامج انسيس في هذا المشروع ، كذلك يتم التركيز على حسابات التصميم والتحليل الهيكلي . يعتمد التصميم علي اربعة محركات لحركة المحاور الثلاثة بعزم ٥.٤ نيوتن.متر. اللحام بالقوس المعدني والغاز النشط الالي يستخدم للوصول الي لحام بين الجودة والتكلفة . بعد تجميع ماكينة اللحام الالي للاجزاء الصغيرة و كبيرة الحجم تعتبرهي الأمثل من حيث التكلفة بالإضافة إلى أن جودة اللحام التى هي أيضا ذات أهمية قصوى ، لذا فإننا نستخدم تقنية اللحام الالي و نحاول تحسين متغيرات اللحام المختلفة والحصول على نوعية جيدة من اللحام وإنتاجية عالية.

Table of Contents

List of Figures

List of Tables

List of Algorithms

List of Abbreviations

3D	three dimension
ANSYS	Analysis System
AC	Alternating current
CAD	Computer Aided Design
CAM	Computer Aided manufacturing
CNC	cOmputer Numerical Control
DC	direct current
FE	Finite element
FEA	Finite element analysis
GMAW	Gas Metal Arc Welding
I/O	input/output
IMAQ	Intelligent Mail and Address Quality
iPac	Infection Prevention and Control
ModIO	Modulator Input Output
MAG	Metal Active Gas
MIG	Metal Inert Gas
MP	Mega pascal
NC	Numerical Control
PC	Personal Computer
PCI	Peripheral Component Interconnect
PLC	Programmable Logic Controller
RPM	Revolution per Minute
USB	Universal Serial Bus
WPS	Welding Procedure Specification
WPQR	Welding Procedure Qualification Record

List of Symbols

η	Efficiency
η_g	Efficiency of gear box
G	Gear Ratio
uts	Ultimate Tensile Strength
Z_{min}	Minimum number of teeth to avoid interference
Z_g	Number of teeth of gear
Z_p	Number of teeth of pinion gear
P	Output power
N	Rotation speed
N_p	Rotation speed of pinion
N_g	Rotation speed of gear
P_i	Input power
P_o	Output power

Chapter one
Introduction

1.1. preface

Welding is defined as the process of joining materials by the application of thermal or mechanical energy. During welding, the edges of the metal pieces are either melted or brought to plastic condition. This process is used for making permanent joints, which is obtained by homogeneous mixture of two materials. Welding finds wide spread applications in almost all branches of engineering industry. It is extensively employed in the fabrication and erection of steel structure in industries and construction. It is also used in various industries like aircraft frame works, railway wagons, furniture, automobile bodies, ship buildings, nuclear industries etc. depending on their application.

Arc welding is usually performed by a skilled human worker who is often assisted by a person called fitter. The working conditions of the welder are typically unpleasant. The arc from the welding process emits ultraviolet radiation which is injurious to human vision. Other aspects of the process are also hazardous. For instance, the high temperatures created in arc welding and the resulting molten metal is inherently dangerous. The electrical current that is used to create the welding arc is also unsafe. During the welding process, sparks and smoke are generated and these make the environment unsafe to the operator.

As a result of these difficulties, robots are being employed on the production line to perform arc welding operations. The robot is programmed to perform a sequence of welding operation on the product as it arrives at the workstation. However, there are significant technical and economic problems encountered in applying robots to arc welding. One of the most difficult technical problems for welding robots is the presence of variations in the components that are to be welded. One is the variation in the dimensions of the parts in a batch production job. This type of dimensional variation means that the arc welding path to be followed will slightly change from part to part. The second variation is in the position of orientation of work piece itself. These two problems can be overcome if we opt for automatic machine system. The automatic machine system provided with a controller. As we know welding process is the part of production process which is very much responsible for the production rate and in turn in its cost of production. So in this project to automate the welding process in a cost effective process. The weld process had been chosen MIG welding because MIG it is the most common welding process with respect to other processes for ability to be mechanized it power and the automated electrode wire feed mechanism. The project aims at developing a much cheaper but effective and advanced gas metal arc welding with automated kit for automating the whole welding process.

1.2. Problem Statement

The main important problems that occur during welding are weld metal porosity, Lack of fusion, faulty wire delivery related to equipment set-up and maintenance, and production rate. Another common MIG welding problem-spatter-occurs when the weld puddle expels molten metal and scatters it along the weld bead, excessive penetration occurs when the weld metal melts through the base metal and hangs underneath the weld, and operators operating mistakes.

1.3. Proposed Solutions

In much the same way that the automatic transmission has simplified the process of driving, Gas Metal Arc Welding (GMAW) has simplified the process of welding. Of all welding methods, GMAW is said to be one of the easiest to learn and perform. The main reason is because the power source does virtually all the work as it adjusts welding parameters to handle differing conditions; much like the sophisticated electronics of an automatic transmission.

1.4. Objectives

Primary objective of invention is to provide a supporting structure having greater capabilities of welding by using constant travel speed during welding process ,in addition provide the good welding quality and high productivity over manually and increasing welder safety .

1.5. Methodology

From literature outcome we inferred that the most suitable assembly for the driving mechanism would be helical rack and pinion. Then we took measurements of the space constraints and referred cost charts for the standard materials used for gears. Next step was to select suitable gear materials by cost comparison and considering the space limitations. After that we designed the system for the dimension limitations with the selected material and selected higher grade material if required ,The dimensions obtained were then used to prepare a computer model in ANSYS for further validation. The last step consisted of fabricated the machine and implementing the some sample of welding using the automatic machine .

1.5.1. Data Collection

According to design matrix based on D-optimal design matrix, the experiments will be conducted on mild steel plate using stainless steel electrodes.

- Empirical Modeling: Development of empirical model (relationship between GMAW responses and the GMAW parameters) using WPS (welding procedure specification) parameters in a MACH3 software.
- Test for accuracy of develop model: Checking of model significance, model terms significance using WPQR (welding procedure qualification record) analysis. This empirical model will helpful in optimal selection of GMAW parameters.
- Optimization of GMAW Parameters: Analysis and selection of optimal GMAW parameters for a low dilution rate.

1.5.2. software tools

- solid work software
- ansys software
- mach3 software
- sheetcam software
- autocad software

1.6. Thesis Outline

The rest of this thesis is outlines as follows. Chapter two presents a background and literature review. Chapter three describe the model of the system of automatic welding machine. Chapter four presents the designed model using Solid Work software, analysis using Ansys software and manufacturing parts, and assemblies of parts. Chapter five contains the conclusion and the recommendations.

Chapter Two
Background and Literature Review

2.1. Introduction

Welding is a manufacturing process for joining of different materials. Unlike other processes, such as casting, forming, machining, etc., which are employed to produce a single component, joining processes are used to assemble different members to yield the desired complex configuration. There is hardly any material that cannot be welded, but not all the materials can be welded using every process. Therefore, the selection of a welding process to accomplish a joint of desired specifications and quality is imperative before undertaking the fabrication task. Some welding processes are known to be associated with specific applications, such as GMAW, extensively used in the sheet metal work to join different materials of different thicknesses.

To ensure high productivity, process control as well as good quality of product, a manufacturing process is to be automated. In order to automate a process, a proper model has to be constructed and tested before implementing process control. MIG welding is an inert gas (like CO_2, CO_2+Ar.) shielded arc welding process using a consumable electrode. Here a relation has to be establishing in between input and output of welding parameter. The idea behind fabrication of low cost Automatic welding machine is to full fill the demand of CNC welding machines for small scale to large scale industries with optimized low cost. In addition to that the quality of the weld is also quite paramount therefore using an optimization technique we try to optimize the different weld parameters and get a good quality of weld. We aim to develop a prototype 3-axis Welding machine using breakout board control system.[2]

2.2. Structural Design

The structure of the automatic machine consists of the following systems: mechanical, drive and controlling. The modular approach in designing is the foundation of design of contemporary machine. The modules are constituent parts of the machine tool.

1. The *kinematic modules* – a module of the main movement (welding torch)
2. and a *module of the linear support* movement in the direction of the NC coordinates have the most important role.

These two modules allow the implementation of the basic function of the machine tool: the relative movement between the tool and the work piece and the realization of the process. Onto the kinematic modules (supports, stands, bearing support system) functional systems are built in: drive systems, the system for leading (sliding and roller guides) and linear movement.[10]

Most of the functional systems can be found on the market as ready-made and can be adjusted fast, with some modification, to the requirements of the projected machining system. This fact in designing of the mechanical system of the 3-axis automatic welding machine was used, therefore the design of the control unit of the 3-axis automatic welding machine was the brunt of this work. Thus, when designing the module of the linear movement in the direction of the NC coordinate axes BOSCH profiles with corresponding cross section and BOSCH guides are used. The relative movement between the modules is realized over worm shaft and nut rack with recirculating ball bearing. Step motors with rotational movement with precisely determined functional characteristics are used to drive the bandages spindle (support linear movement). 3D model of the lab 3-axis automatic machine. The module of the X axis (basic module of the support structure). The module of the Y axis (gantry module). The module of the Z Axis The module of the main spindle torch consists of several basic functional parts: welding torch, spindle shaft, axially spaced roller bearings and electric drive motor.[12]

2.2.1. Rack and Pinion

It is a type of linear actuator that comprises of a pair of gears which converts rotational motion into linear motion. A circular gear called pinion engages teeth on a linear gear bar called the rack. Maximum travel R&P is required for longer axes; much larger motors are then required to achieve acceptable speeds. This is where R&P really shines. The system can be used to create axes of arbitrary length, limited only by the length of the linear rail guiding the system. Racks are typically available in 6' and 12' sections, and if necessary can be spliced to create extremely long travels. The fixed cost of the drive system and the relatively low cost of cold rolled steel and gear rack make the cost per foot of travel highly competitive for larger travels. Accuracy Many people assume Acme is more accurate than R&P, as a screw driver typically has more resolution than our R&P units. whereas our NEMA 23 R&P with the same driver has an effective resolution of around 0.0005". However, both of these resolutions are more than adequate for large format cutting, and inaccuracies at other points in the system (such as screw lead error and backlash) make these differences more or less irrelevant. Speed There is an appreciable difference in speed between the systems due to gearing. The R&P is geared more aggressively to better utilize the low-end torque of stepper motors, and is also more mechanically efficient systems.[14]

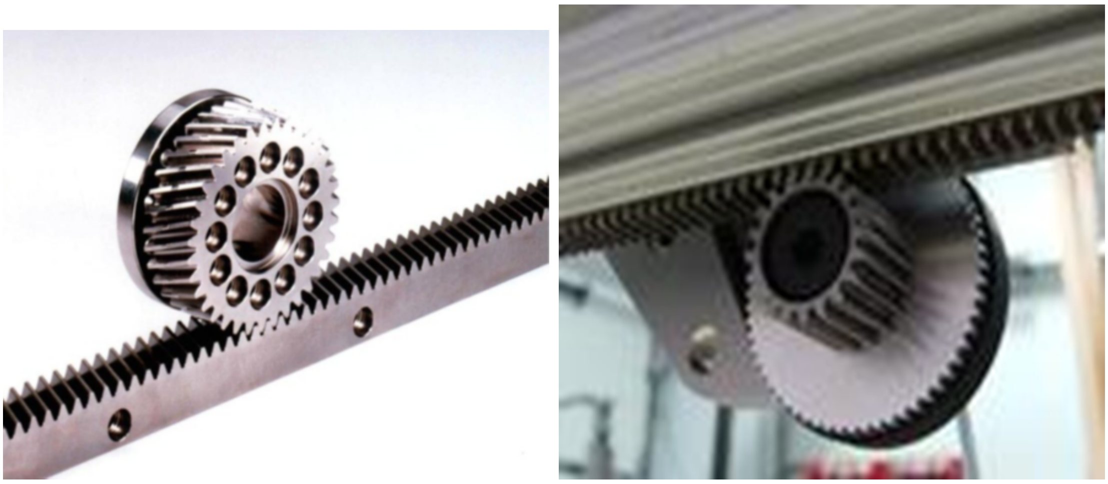

Figure 2.1.: Rack and Pinion [1]

2.2.2. Linear Guide

Linear guideways provide linear motion by re-circulating rolling elements between a profiled rail and a bearing block. The coefficient of friction on a linear guideway is only 1/50 compared to a traditional slide and they are able to take loads in all directions. With these features, a linear guideway can achieve high precision and greatly enhanced moving accuracy. Linear guide ways provide a reduced co-efficient of friction along with increased acceleration and deceleration rates. They are used by machine builders because they provide higher speeds and rapid rates. However, the advantage of higher rapids comes at the expense of dynamic stiffness which affects component accuracy during dynamic machining conditions.

Linear guide ways have the great advantage that the replacement of these guide ways requires less skill and can be done by any good maintenance engineer with some exposure to machine tool alignments and repair. The time taken for replacement of linear guide ways is substantially lower than that of box guide ways. Linear guides require less accurate machining and surface preparation for mounting as compared to the box way's top plate and bottom surfaces which have to be ground and hand scraped to very high accuracy levels so that they match precisely. Guide ways of linear systems are relatively small as compared to the large surface areas of box ways. Hence, larger machines requiring more robustness are predominantly built with box guide ways.

Box guide ways require the fine art of hand scraping to obtain the required geometrical specifications. The "Scraper Hand" literally scrapes the metal with carbide tipped scraping tool. The repetitive exercise of rubbing the slide to replicate the way profile produces contact points or "bearing". Great care is taken to equally distribute the load carrying points. Power spotting is performed at the completion of the scraping process and produces the half-moon appearance that insures adequate channels for oil distribution. This hand scraping work requires skill which is mastered over years. Box ways offer a great advantage over linear motion guide ways with respect to rigidity and load. In addition, box guide ways have a vastly superior vibration damping capacity over linear motion guides. They can be used even on very severe machining applications such as hard milling of pre-hardened steels and high nickel refractory aerospace alloys. A further bonus with rigid box way machine tools is that they increase the life of today's carbide and ceramic tooling by damping the vibration that can break tooling. Box guide ways allow customers to push the part-load envelope, simply by reducing the rapid rates. Hence box guide ways are always preferred when the application needs high load capacity, heavy rigidity, higher tool life, better vibration damping and ability to machine tough materials.

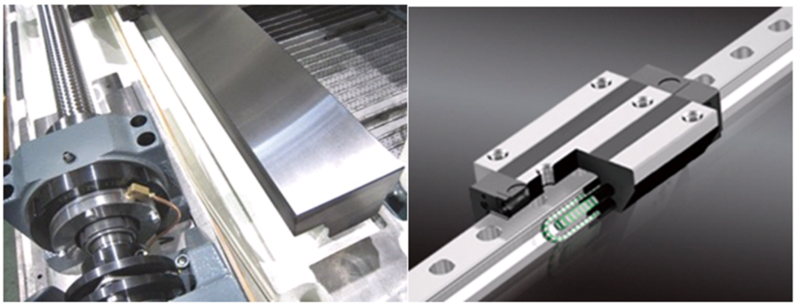

Figure 2.2.: Linear Guide [2]

2.2.3. Stepper Motor

A stepper motor is a special type of electric motor that moves in precisely defined increments of rotor position (Steps). The size of the increment is measured in degrees and can vary depending on the application. Due to precise control, stepper motors are commonly used in medical, satellites, robotic and control applications. There are several features common to all stepper motors that make them ideally suited for these types of applications.

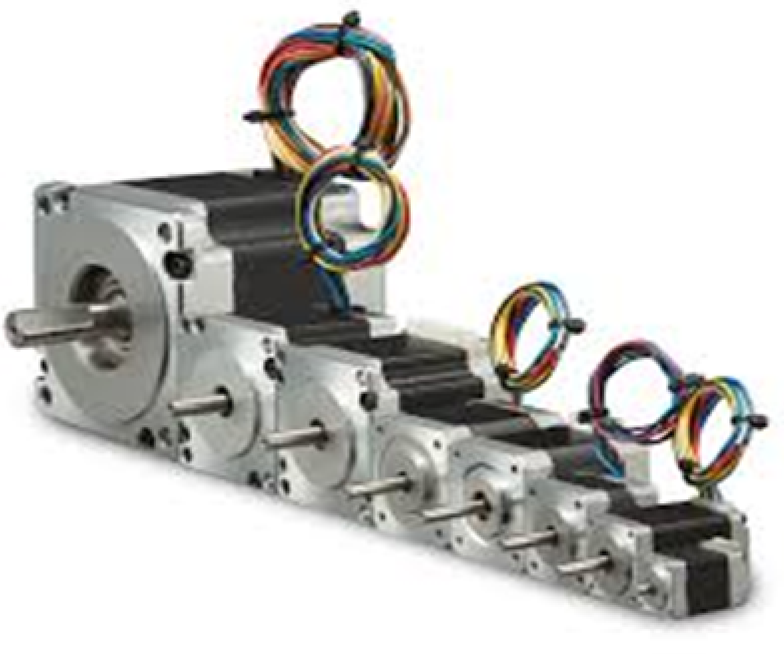

Figure 2.3.: Stepper Motor Model from Kollmorgen [3]

Figure 2.4.: Stepper Motor with 200 steps/rev, 600mm Wire [4].

2.2.4. Control Unit

The control unit is to enable direct entry of the G code and reading of the codes over USB interfaces, and to generate control signals for step motors based on the code. The control unit is based on a PC platform along with ARDUINO microcontrollers for every controlled axis. The interface between a machine and an operator is realized over controlling tasters and computer screen, and with the help of the interface the operator can access different regimes of programming and work of the machine, but also access and control auxiliary functions of the machine. The relative movement between the tool and work piece of the automatic machine is defined with the resultant which consists of the components of the movements in direction of axes of the coordinate system of the machine.[15]

2.3. Related Studies

The related approaches include design of automatic Welding machine based on PLC. This method presents an automatic welding machine used for the carbon dioxide gas welding, with the mechanical structure designed, and the working process of the automatic welding machine analyzed. Experimental operation results show that PLC-controlled automatic welding machine can improve welding quality and efficiency, reduce labour intensity and bring huge economic benefits [5]. Other methods include forward and reverse modeling in MIG Welding process using fuzzy logic-based approaches. It is an attempt to carry out the forward and reverse modeling of the MIG welding process using fuzzy logic-based approaches [6].

Automatic welding system can be classified into two categories namely:

- System based on contact sensors
- System based on noncontact sensors

The study in [7] focuses on the latter. There are three categories of non-contact sensors :

1. Systems based on voltage through the arc welding.
2. Systems based on ultrasonic sensors.
3. Systems based on visual sensors.

Maqueria et al., [8], developed an ultrasonic based robot to track the seam. He used an ultrasonic sensor which is interfaced to a P-50 process robot in an effort to achieve on-line seam tracking of joints, without the use of geometrical models or subsequent "teaching" routines. Also,Li, et al., [5] designed an automatic welding machine based on PLC. He designed the machine to perform carbon-di-oxide gas welding.

Gas metal arc welding (GMAW) or as called metal inert gas (MIG) is used for welding pipeline, which is a semi-automatic arc welding process. Machine that hold and carry the welding gun of the MIG machine moving on a circular rail fixed near the pipe groove, can helpfully to improve the welding finish compared with the manual process by maintaining in parameters of welding such as keep the distance between the gun and the groove of weld joint, constant travel speed of the welding gun, also saving in time and funds [9].

The study in [9] beings with an introduction to welding the various components automatically. Two pneumatic cylinder and Solenoid valve are used. Cylinder is for the forward and backward movement, it moves in both x and y axis. So, it is called as *double axis welding machine*.

In [10], a 3-axis robotic arm has been modelled using CAD tool for performing welding operations. For the developed robotic arm, forward & inverse kinematic analyses have been performed to move the weld torch in the desired trajectory. A new seam tracking methodology, named sewing technique has been introduced for the welded joints available in Computer Aided Design (CAD) environment. This methodology, gives the seam path by drawing a line through the adjacent centroids of curve fitted in the weld joint volume. Obtained geometric path and kinematic constraints are given as input to the modelled robot for performing welding operation followed by desired trajectory. Validation of the developed methodology has been done through simulation results while performing welding operations for different weld profiles.

The welding Positioner with auto indexing which is very important for mass production industries related with circular welding [11]. As it depends upon the skill of worker to move electrode along the welding line. This special device can rotate the job at fixed rate to assist the welding process for circular components and ensure good profile and homogenous welding. This model has applications in small cylinder welding, compressors, and bottle filling plants etc. Automated welding Positioner machine for circular weld is totally satisfying the requirements. For this system Worm and worm wheel, Commutator motor, Belt drive, Proximity sensor, Ball bearing, Electronic relay, inching switch, inputs are required.

For the continuous welding problem of multi-T-tube radiators' intersecting line, a new type of two-welding torch automatic welding machine is designed in [12]. The design scheme of the welding machine is described, and its main mechanisms are designed. Using three-dimensional software, its model is built. Motion simulation and interference checking are carried out based on interpolation. The fact welding test shows: the intersecting line is accurately welded and the production efficiency and welding quality is enhanced.

In the last years, efforts have been focused towards new approaches for the automation of gas metal arc welding process parameters. In this framework, an innovative welding system based on a 3-axis motion device and a vision system consisting of a video camera, a laser head and a band-pass filter has been developed in [13] and implemented to recognize the desired features of weld joints, such as geometry and dimensions, and automatically adapt the welding process parameters according to these features.

The proposed study in [14] aims at designing the low budget automatic welding system which is semi-automatic in nature for automatic guided welding of 'V' groove and 'F' fillet weld in pressure pipes using sensor controlled and Programmable Logic Controller(PLC) based system economically. The suitable sensor detect weld zone parameters and PLC is used to control the output of sensor. Welding system automatically position welding torch and do welding for multiple pass. Gas Metal Arc Welding (GMAW) is used for carbon steel pipe. Finally, performance of welding is evaluated through quality check by National Accreditation Board Laborites accredited Lab and cost of welding system is compared [5].

Also, design and fabrication of a 2D welding machine is presented in [15]. The MIG welding machine has a relay switch to control ON/OFF operation of welding torch. The essential feature of the process is the small diameter electrode wire, which is fed continuously into the arc from a coil. The base metal used for welding is carbon steel. Through this report our effort will be to completely eliminate human contact during welding which will no doubt be safer but will also be more efficient. The machine is used to weld work pieces in flat position since higher deposition rates are achieved in this position and is a convenient approach. The project will be able to weld any contour in 2D profile that is generated over a graphic user interface in addition to butt, edge, and lap joints. Electronic devices such as stepper motors and driver board are interfaced with microcontroller board. The microcontroller Arduino Uno at mega 328 is used to signal the stepper motors to rotate while deciphering the G-code. GRBL version 8.0 is used to transform "Arduino" into G code interpreter.

Finally, Finally, the study in [16] is about the development of automatic inspection system of welded nuts on support hinge used to support the trunk lid of a car using machine vision system. Until now, inspection of welded nuts was being performed manually visual inspection by worker in projection welding process. So it caused the production of poorly-made parts. The conditions of poorly-made parts divided into two categories; an omission of nuts, an eccentricity of welded nuts. These parts make trouble to erect between support hinge and the lid of trunk. To improve demerits of this manual operation, automatic inspection system using machine vision system is introduced. Inspection process is performed to make the complete vision based automatic inspection system before assembly, and this procedure led to the manufacturing cost saving. As the inspection algorithm, template matching algorithm (pattern matching and geometric matching techniques in NI IMAQ VISION) is applied to distinguish the articles of good quality and the poorly-made articles. Main panel of developed vision program is programmed by NI Lab-

VIEW software. Main program contains operating mode and setting mode compensating minimum matching score about the variation of the lighting condition.[8]

Chapter Three
Modeling Approach

Part I.

3.1. Introduction

By developing and applying automatic welding machine a big progress, with an efficiency in preparation, organization and performance of welding operation, is made. Automatic welding machine is controlled by a computer, that is by a computerized control unit that is placed on the machine. As the control unit contains of a computer, programs can be saved, modified and upgraded, and the results of these intervention can be simulated and verified instantly on the machine, before production began. Programming of the automatic machine is made via a computer, and the program is most often transferred with a USB storage device or through a computer network. There is also the possibility to program directly on the machine using the keyboard and screen, that are components of every automatic machine. The control unit support 2D geometric models as there are the basic of automatically generating of programs. The goal of this work is to design a 3axis automatic welding machine by using a modular approach [17].

3.2. Functional Modules of the Automatic Machine

As reported in [17], the structure of the automatic machine consists of the following systems: mechanical, drive, measuring and controlling. The modular approach in designing is the foundation of design of contemporary machine. The modules are constituent parts of the machine. The kinematic modules – a module of the main movement (module of the main spindle) and a module of the linear support movement in the direction of the NC coordinates have the most important role. These two modules allow the implementation of the basic function of the automatic machine: the relative movement between the welding torch and the work piece and the realization of the process. Onto the kinematic modules (supports, stands, bearing support system) functional systems are built in: drive systems, the system for leading (sliding and roller guides) and measuring systems for circular and linear movement. Most of the functional systems can be found on the market as ready-made and can be adjusted fast, with some modification, to the requirements of the projected machining system. This fact in designing of the mechanical system of the 3-axis automatic machine was used, therefore the design of the control unit of the 3-axis automatic machine was the brunt of this work.

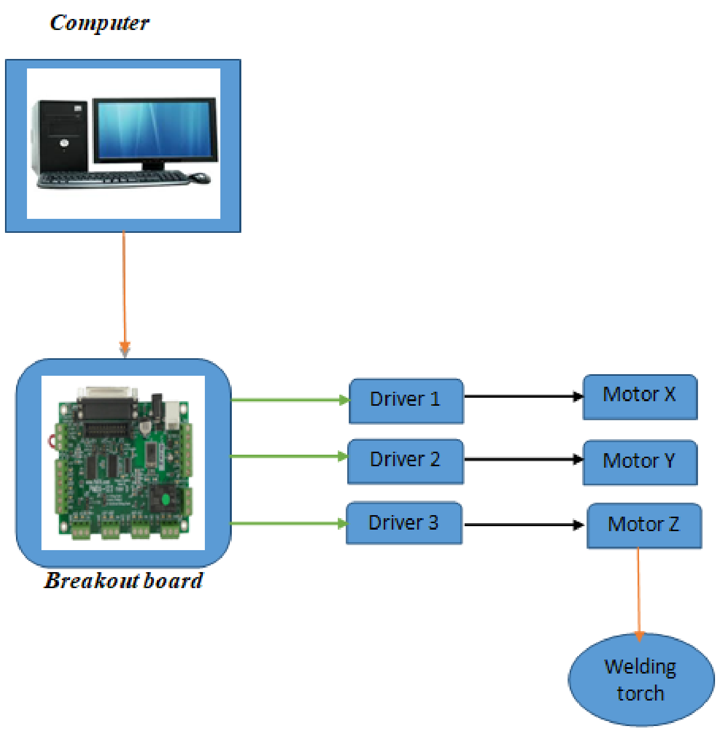

Figure 3.1.: System of automatic machine. Breakout board Photo from [18]

3.2.1. Breakout Board

A breakout board "breaks out" these pins onto a printed circuit board that has its own pins that are spaced perfectly for a solderless breadboard, giving you easy access to use the integrated circuit.

The Breakout Board is used to interface between your PC and the various motor controls, relays, and other devices you want to control on a CNC machine. There are several different types of CNC Breakout Boards and related devices used to deliver this I/O (Input/Output) capability, including Parallel CNC Breakout Boards, USB Breakout Boards, keyboard emulators, and motion control boards. Simply put, the CNC Breakout Board has two functions:

- Translate the signals used to run a CNC machine to and from the signals a PC expects.
- Isolate the PC Motherboard from electrical problems that would otherwise fry the Motherboard.

These are both very important functions. In addition, many refer to USB Motion Controllers, such as the Smooth stepper, as "USB Breakout Boards".

The role of a Motion Control is to relieve your PC control software from having to do all the work and move some of the most time critical parts of that work to a dedicated hardware device. Since the Motion Controller has no distractions (unlike a PC), and can focus totally on motion control, this enables much higher performance [19].

Parallel CNC Breakout Boards connect to your PC's parallel port and convert those signals to screw terminals which you may then use in point-to-point wiring to connect up the rest of your system. These are the most commonly used type of breakout board. They're simple, and relatively inexpensive. They have a few drawbacks. First, the parallel port itself is a bit of a throwback to the early days of the PC. There are limitations on its performance, particularly when used with Windows software, such as with Mach 3. You will be limited in how quickly you can send and receive the signals from the board, which may in turn limit the performance of your CNC. For most low end applications, this is not a problem. For better performance, use a Motion Controller (see below).

The second limitation is that of compatibility. PC manufacturers are gradually phasing out parallel ports altogether in favor of USB, and in the meantime, they are sharply controlling the power consumption of these interfaces. As a result, many later model PC's use 3.3 volt signals instead of 5 volts. Some breakout boards work fine with this while others have problems. Be sure to check whether the board you are looking at will be compatible with your PC. Laptops are a particular source of this kind of problem. Lastly, parallel ports have relatively few I/O channels. Boards typically support 11 or fewer outputs and only 5 inputs. As you can imagine, these go quickly, especially if you are trying to connect an elaborate control panel to your machine. For this reason, you either have a choice to "keep it simple", or you will need to add one or more additional boards to get the job done [20].

It should be noted that you can add a second parallel port to most computers using a PCI card. Obviously this won't work with a laptop, because they have no PCI slots. In addition, some card/PC combinations can be finicky when used with Mach 3. Be sure to check with others to see if they have been successful with the particular combination you'd like to try.

Lastly, it is important to purchase a board that incorporates opto-isolation (you can look it up in the CNC Dictionary if you are curious). This feature isolates your PC's motherboard from any bad connections, noise, or power surges that may occur in the rest of your circuitry. If you directly connect the parallel port without opto-isolation, you run the risk of destroying your computer's expensive motherboard.

USB breakout boards come in two varieties. First are full scale Motion Controllers, which we will cover in detail in a moment. Second are boards used to increase the I/O capacity beyond what the parallel port provides. While there are boards that purport to simulate a parallel port with a USB connection, they don't work for CNC applications. The reason is that they are not high enough performance to maintain the exact timing relationships needed to produce a clean pulse train to control multiple servos or steppers. Unfortunately, while USB is the preferred replacement for the parallel port, and it has many advantages, it isn't clear applications like CNC were considered for either the parallel or serial ports when they were first designed. It takes some very clever coding indeed for software like Mach3 to work on a parallel port, and each new release of Windows seems to make it a little harder. the only USB Breakout Board I am aware of intended solely to increase I/O capacity is one called ModIO that was developed by an Australian company called HomannDesigns. This board is capable of adding 8 inputs, 8 outputs, as well as 3 analog inputs, so it is quite powerful. This board is very well supported by the CNC community, so if you need the extra I/O, I would highly recommend it. I've dealt with Peter Homann on occasion and he is extremely helpful and works hard to give what he can to the CNC community. There are USB boards (the Smoothstepper is one) that can actually generate step and direction pulses suitable for CNC, but these are more properly motion controllers than breakout boards [20].

3.2.2. Keyboard Emulators

Keyboard emulators are another approach to extending the basic I/O provided by a parallel breakout card. They do this by converting on/off input signals to simulated key sequences. For example, you could connect a switch labeled "Flood Coolant On" to an input on a keyboard emulator and when the switch closed, it would forward a key sequence to Mach 3 which could be interpreted to turn on the coolant. Keyboard emulators are simple to hook up: they typically accept your keyboard's plug and you use a keyboard extension cable to go from the emulator to the PC's normal keyboard input socket.

There are a number of keyboard emulators out there, but I believe the most

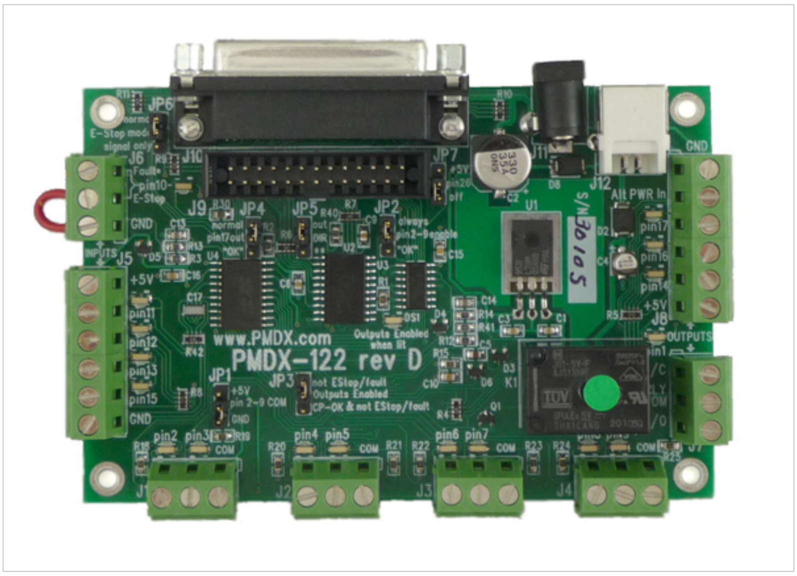

Figure 3.2.: Breakout Borad [18]

popular are Pokeys and the iPac, which is sold Ultimarc. The basic iPac provides an additional 28 inputs, which is substantial. There is an enhanced version that allows 56 inputs. Pokeys is a 55 I/O channel device. The thing about Keyboard Emulators is that since they're just sending key sequences, they have a pretty slow response time. You wouldn't want to use one for any application that required rapid responses or a good sense of "touch" or "feel". For example, I would tend to avoid using them with joysticks. But they are a good way to pick up all the extra buttons on your control panel. Motion Controllers (USB Breakout Boards) At the high end of the breakout board spectrum are the motion controllers. They are so high their makers probably object to comparing them to breakout boards. I only do so because they replace the breakout board. Mach3 works with several, including the Smooth stepper (probably the most popular as I write this), the Galil, and others. These boards offer a tremendous performance upgrade over parallel boards and the like. Their primary disadvantage is they're a less mature technology. Since they haven't been with us for long, and since most of the Mach community is using parallel ports rather than motion controllers, you may find it is a little harder to get help. I have a smooth stepper, which has worked great [21].

3.2.3. Drivers

Drives Basic function of aCNC machine is to provide automatic and precise motion control to its elements such work table, tool spindle etc. Drives are used to provide such kinds of controlled motion to the elements of a CNC machine tool. A drive system consists of drive motors and ball lead -screws. The control unit sends the amplified control signals to actuate drive motors which in turn rotate the ball lead -screws to position the machine table or cause rotation of the spindle

3.2.3.1. Power Drives

Drives used in an automated system or in CNC system are of different types such as electrical, hydraulic or pneumatic. Electrical drives are direct current (DC)or alternating current (AC)servo motors. They are small in size and are easy to control. Hydraulic drives have large power to size ratio and provide step less motion with great accuracy. But these are difficult to maintain and are bulky. Generally, they employ petroleum based hydraulic oil which may have fire hazards at upper level of working temperatures. Also hydraulic elements need special treatment to protect them against corrosion. Pneumatic drives use air as working medium which is available in abundant and is fire proof. They are simple in construction and are cheaper. However, these drives generate low power, have less positioning accuracy and are noisy. In CNC, usually AC, DC, servo and stepper electrical drives are used. The various drives used in CNC machines can be classified as:

- Spindle drives to provide the main spindle power for action.
- Feed drives to drive the axis.

3.2.3.2. Hydraulic Drives

These drives have large power to size ratio and provide step less motion with great accuracy. But these are difficult to maintain and are bulky. Generally, they employ petroleum based hydraulic oil which may have fire hazards at upper level of working temperatures. Also hydraulic elements need special treatment to protect them against corrosion.

Figure 3.3.: drivers [28]

3.2.3.3. Pneumatic Drives

This drives use air as working medium which is available in abundant and is fire proof. They are simple in construction and are cheaper. However, these drives generate low power, have less positioning accuracy and are noisy. In CNC, usually AC, DC, servo and stepper electrical drives are used. The various drives used in CNC machines can be classified as:

- Spindle drives to provide the main spindle power for action.
- Feed drives to drive the axis.

[34]

3.3. Mach3 controller software

Mach3 CNC Controller software will convert your PC into a fully functional 6 axis CNC Controller. Mach3 is one of the most popular CNC Controllers for both DIY and Industrial machines. Mach3 works on most Windows PC's to control the motion of motors (stepper servo) by processing G-Code. Mach3 is a feature rich program which is also easy to use. It works with other programs and will import DXF files, generate G-Code, fully customizable. Works with CNC Routers, Milling Machines, Lathes, Plasma Cutters and Lasers [35]. The main components of a CNC system are listed as follows

Figure 3.4.: drivers [28]

- A Computer Aided Design/Computer Aided Manufacturing (CAD/-CAM) program. The part designer uses the CAD/CAM program to generate an output file called a part program. The part program, often written in "G Code," describes the machine steps required to make the desired part. You can also create a G Code program manually.
- A file transfer medium such as a USB flash drive, floppy disk, or network link, transfers the output of the CAD/CAM program to a Machine Controller.
- A Machine Controller. The Machine Controller reads and interprets the part program to control the tool which will cut the work piece. Mach3, running on a PC, performs the Machine Controller function and send signals to the Drives.
- The Drives. The signals from the Machine Controller are amplified by the Drives so they are powerful enough and suitably timed to operate the motors driving the machine tool axes.
- The machine tool. The axes of the machine are moved by screws, racks or belts which are powered by servo motors or stepper motors.

Part II.

3.4. Specification and Steps of Design

The specifications are summarized in table 3.1. The following design steps will be employed as follows.

- Design all parts of machine by using solid work program.
- After design process is completed the axis movement and total installation of machine (critical parts) are analyzed using ansys software.
- Then manufacturing all component parts of machine in workshop.
- Finally, the machine will be made by assembling parts.

Table 3.1.: Specifications of Machine

Specifications	Descriptions
Dimensions(x,y,z)	160 × 125.5 × 132.5 cm
Cross sectional area	125.5 × 132.5 cm
Work area	105.5 × 126 cm
Material	structural steel
Welding torch	form welding machine
Stepper motor	863522 17 12V 5A
Driving system	rack and pinion
Controller	breakout board
Driving motor	railway guide
Function	Welding, engraving and marking. Supply: 220V/50-60 Hz
Interface	USB port
Software	Universal Gcode sender, AutoCAD, sheet cam and MACH3

3.5. Main Components of Machine

3.5.1. Machine Table

A Table is the main base of the machine on which the parts are installed. This table has a four basic legs to fixing the machine on the ground by bolts, any leg has a four bolts. The rack and pinion gear of the horizontal axis are fixed on this table. shown in figure 3.5. The table is among the critical component of the machine tool upon which all the weight and dynamic motion force are acting. The should act as a vibration damping system but at the same time the weight of the bed should not increase to keep it with permissible cost and overall weight of the machine.

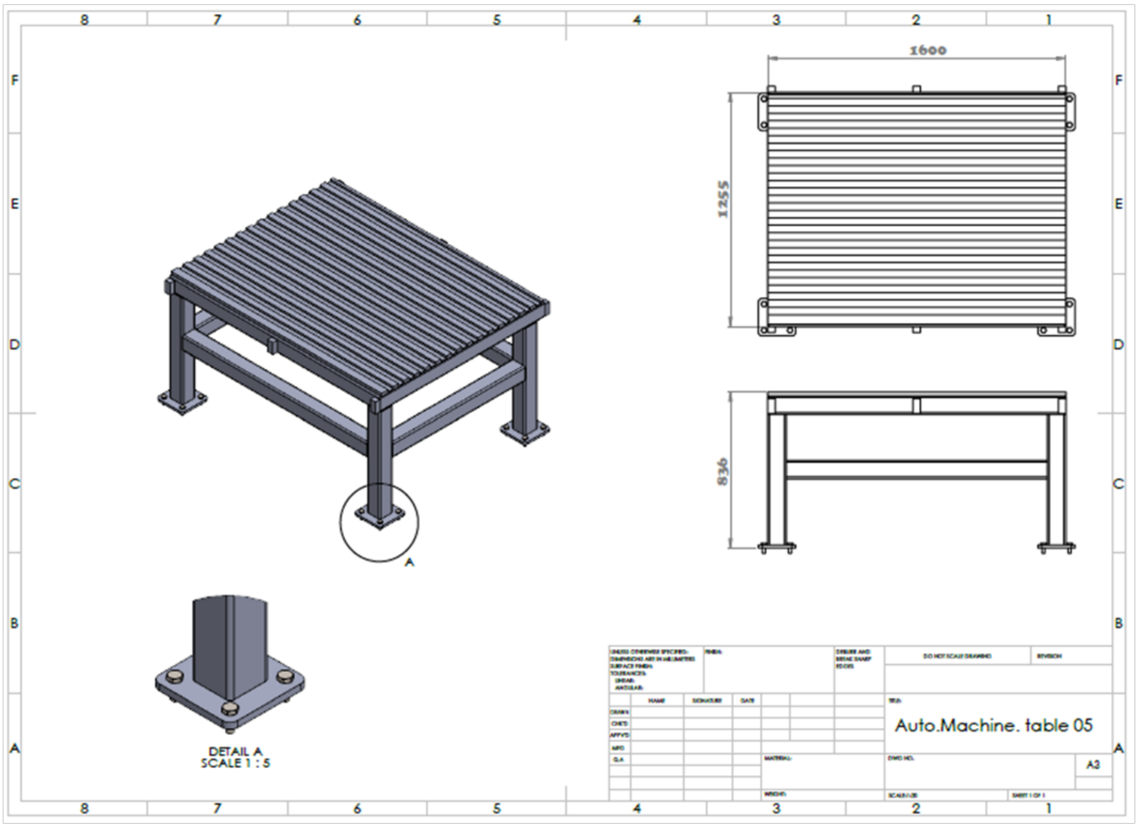

Figure 3.5.: main table of machine

3.5.2. Design of machine X Axis

It is the longest axis of machine with a 1.6 meter length ,the movement of axis depends on the electrical motor which connect with a pinion gear and the pinion gear is engage with rack to do motion of axis. Show in figure 3.6.

3.5.2.1. X-Axis Drive Selection

The selection of X-axis traverse were as similar as that of Y-axis and Z-axis drive except the selection of slide way. The slide way is not under any bending moment in case of X-axis and is only under direct compressive load in which the material shows very good strength.

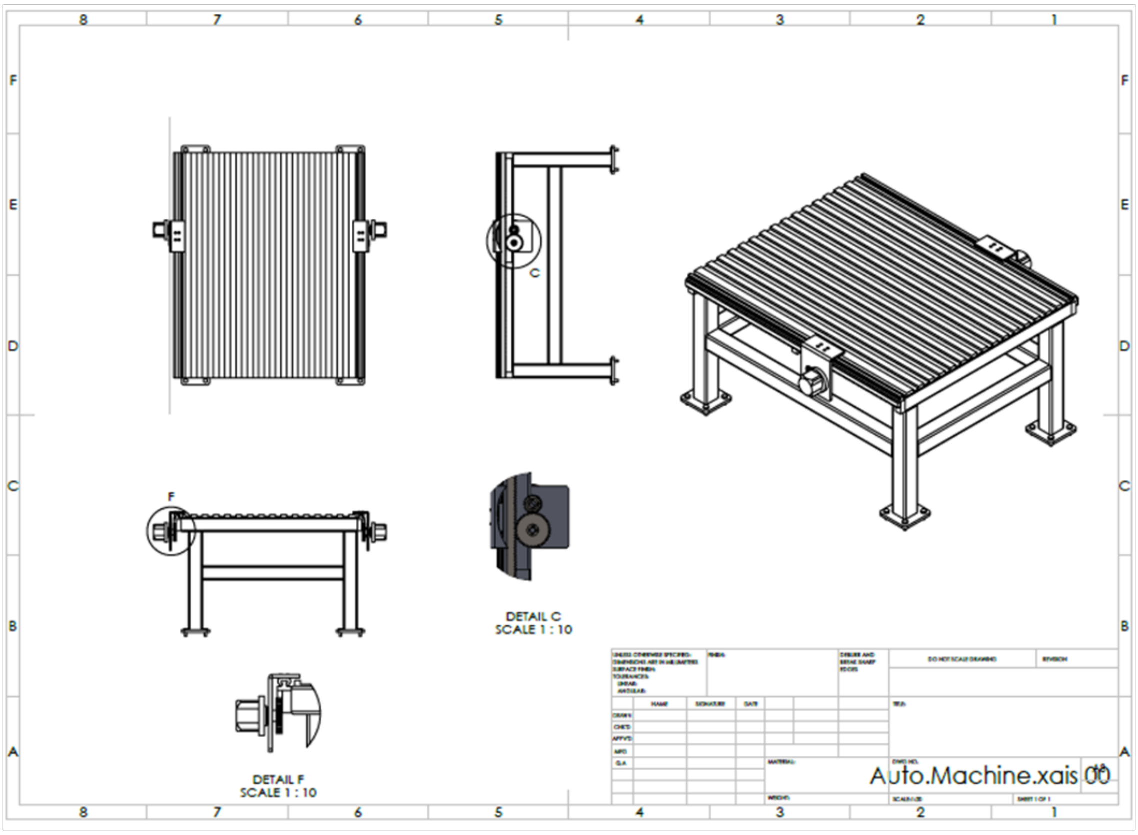

Figure 3.6.: X-axis of automatic machine

3.5.3. design of machine Y-Axis

Same like the horizontal axis, but it is less than x-axis in length(1.405 meter). The y-axis is fixed on x-axis by linear guide(slide way),which facilitates the movement of the axis as shown in figure 3.7.

The Y-axis drive selection will be carried out same as that for Z–axis but the drive length of the Y – axis is very large as compare to Z and it is also supporting the Z-axis assembly.

Therefore components selection will be having hire rating of that of Z-axis.

3.5.3.1. Selection of Slide Way

As the selection of the slide way for Y- direction depends upon the bending moment, from the figure 3.7 we will calculate a rough dimension choosing the smallest CAD model as shown in figure 3.7

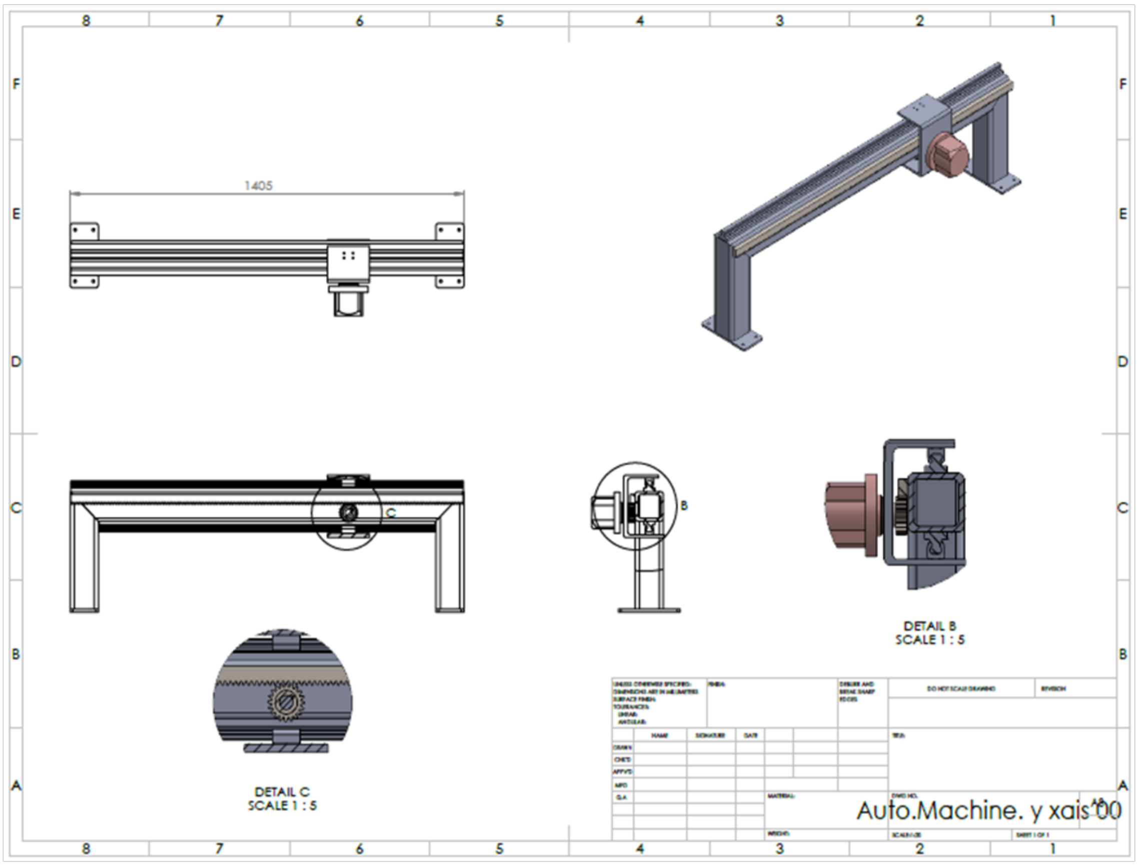

Figure 3.7.: Y-axis of automatic machine

3.5.3.2. Selection of Driving Motor

The driving torque in Y-axis will not be influenced with the gravity torque. The Drive motor selected for the Y-axis drive is calculated in figure 3.7.

3.5.4. Design of machine Z-axis

Axis of vertical motion, it has a limited movement which the arc length of the welding process is controlled by it, the arc length of welding depend on the distance between the welding torch and the part which should be welding as shown in Fig 3.8. The Z-axis slide way carries the torch of welding and the bracket arrangement and is under the direct effect of the welding penetration.The Z-axis slide has to move very rapidly and is under motion in every process.

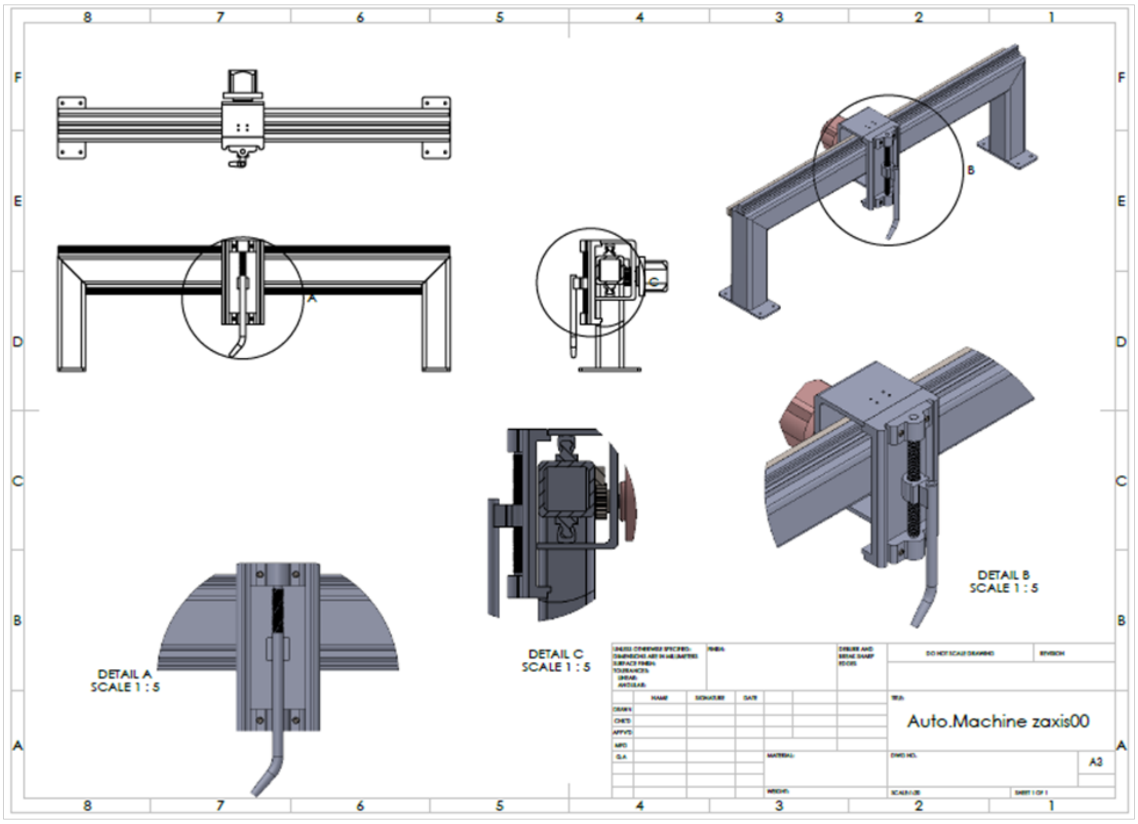

Figure 3.8.: Z-axis of automatic machine

3.6. Automatic Welding Machine Full Design

The full CAD design of the automatic welding machines is depicted in figure 3.9. The figure shows difference view of the table. The equivalent shape fro the workshop is presented in figure 3.10.

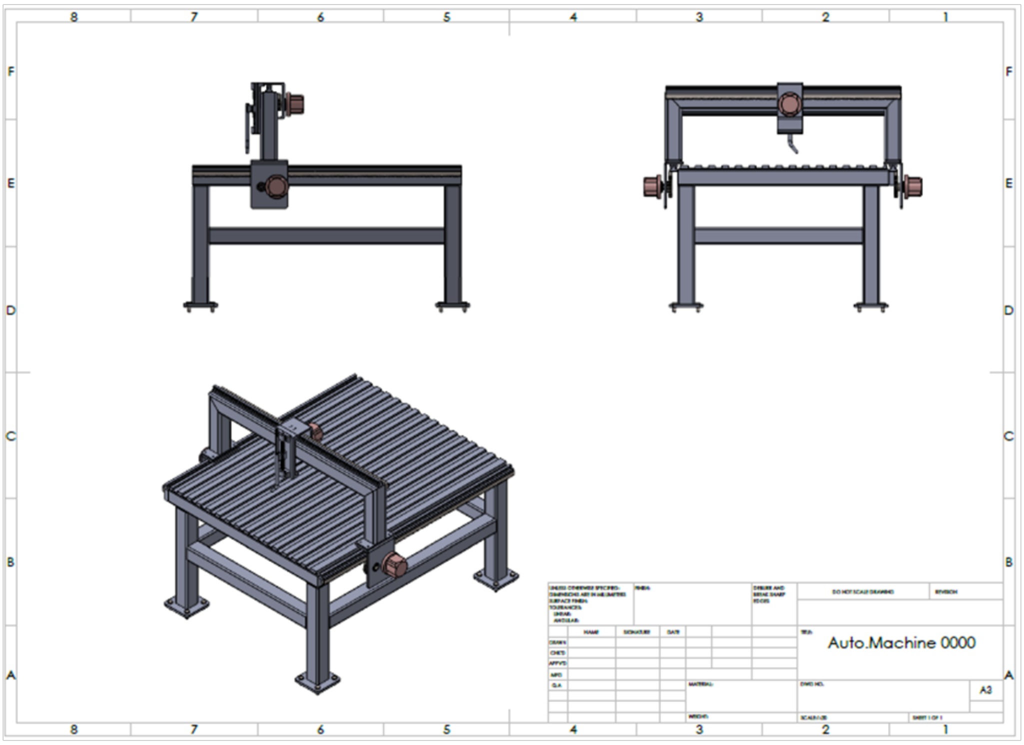

Figure 3.9.: Automatic welding machine - CAD design

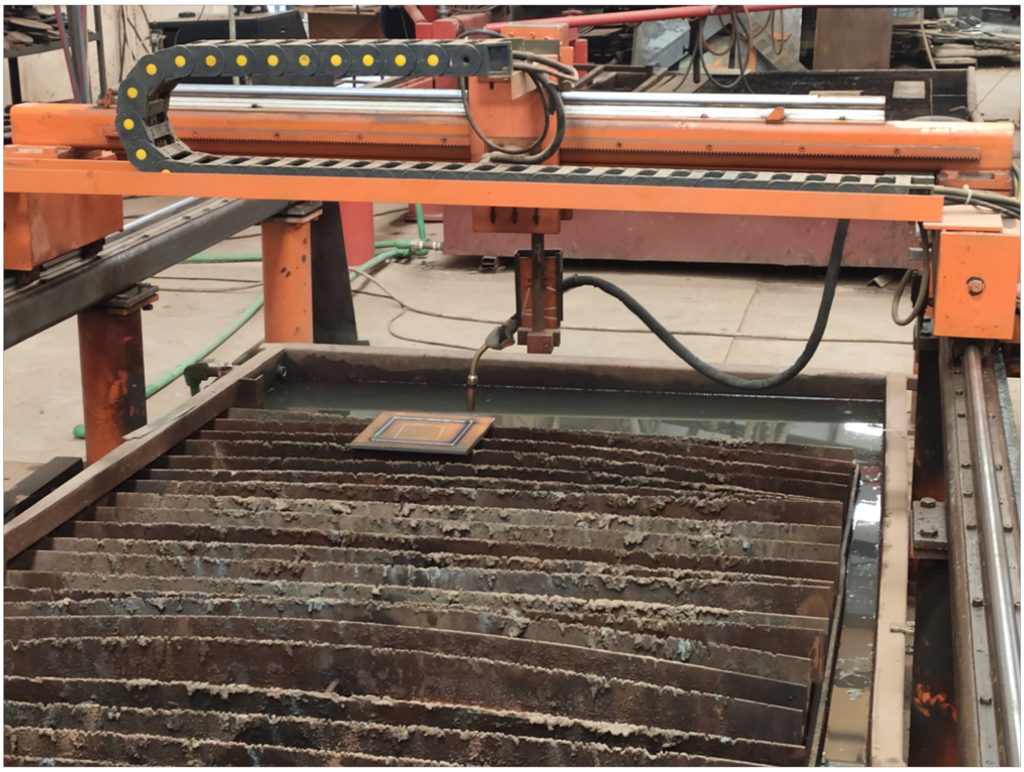

Figure 3.10.: Automatic welding machine in workshop

3.7. Mathematical Calculations

Power provided by the prime mover will be sufficient enough to carry out the operation to be done and how much is the output power required. The assembly at the company is driven by an electrical motor with the rating, 0.75 kW at 2000 RPM, through a worm reducer gearbox with 3:1 reduction ratio. Therefore, the output speed from the gearbox can be calculated by

$$G = \frac{Z_g}{\text{No. of teeth}} = \frac{N_p}{N_g} \tag{3.1a}$$

$$G = \frac{3}{1} = \frac{N_p}{N_g}. \tag{3.1b}$$

The output power and essentially the torque available from the gearbox must be sufficient to be able to drive assembly. The efficiency of the motor is 78%. The efficiency of the reduction gearbox lies between 88% and 94%. Hence, assuming the efficiency of the gearbox to be 90%, the output power can now be calculated as,

$$\begin{aligned} \text{Output power} =& \text{Input power} \times \text{efficiency of the motor} \\ & \times \text{efficiency of the gearbox} \qquad (3.2a) \\ =& 0.75 \times 1000 \times 0.78 \times 0.9 \\ =& 526.5 \quad (W) \\ =& 0.5625 \quad (kW). \qquad (3.2b) \end{aligned}$$

The power is given by,

$$P = \frac{2\pi NT}{60}, \quad (W). \tag{3.3}$$

The RPM can be calculated by,

$$N = \frac{60P}{2\pi T} = \frac{0.5265 \times 1000 \times 60}{2\pi(4.3)} = 1170 \quad (RPM) \tag{3.4}$$

$$Ng = \frac{1170}{3} = 390 \quad (RPM). \tag{3.5}$$

The next step is to check whether the available torque is sufficient to move the assembly and also to check whether the output power available is sufficient to move the assembly highest speed required.

The assembly uses MAG welding method for welding canisters. The MAG welding uses a transformer with a wire roll attached to it. The wire is used during welding continuously. Fully loaded wire roll weighs 20 kg. The weight of the transformer with the fully loaded wire roll weighs 30 kg. Assuming the weight of the assembly which moves with the transformer to be 50 kg, it is necessary to check whether the torque

Available from the gearbox is sufficient to move the complete assembly about 50 kg. The maximum velocity permissible for MAG welding is 0.45 m/s. The power required to move the assembly of 50 kg is calculated by,

$$\text{Power} = \text{Force} \times \text{Velocity} = 50 \times 9.81 \times 0.45 = 220.725 \quad (W) = 0.22072 \quad (kW) \tag{3.6}$$

Therefore, it is concluded that the power output from the gearbox is sufficient to move the assembly at its maximum velocity. Calculating the torque,

$$T = \frac{60P}{2\pi N} = \frac{0.2207 \times 1000 \times 60}{2\pi \times 390} = 5.4 \quad N.m \tag{3.7}$$

Already we were use two motors one motor in each side for moving the weight. Thus, it is also concluded that the torque output from the gearbox is sufficient to move the assembly.

3.7.1. Design Procedure

Let $P = 0.75$ KW, $N = 1170$ rpm, $\eta = 78\%$, denote the motor rating parameters. Also, let $G = 3 : 1$, $\eta = 90$ denote the gearbox rating parameters. Then, the input motor Gearbox output

$$\text{input Power} \times \eta_g = \text{output power}, \tag{3.8}$$

which yields

$$P_o = \eta_g \pi = 0.5265 \quad (kw) \tag{3.9}$$

On te other hand, the speed can be calculated using

$$G = \frac{N_{motor}}{N_{pinion}} \tag{3.10}$$

where $N_g = 390$ rmp and $N_p = 1170$ rpm. Selecting 40C8 as the material for gears since it is the cheapest material meeting the stress requirements.

3.8. Analysis of design

Analyzed important location in machine which it the critical point in design to be sure it has not significant affect for the design.

3.8.1. The Result of Analysis for Critical Point Using Ansys Software

The finite element method is the technique for obtaining approximate numerical solution to boundary value problems to predict the response of physical systems subjected to external loads. In general finite element analysts(FEA) begins by generating finite element (FE) model of a system. In this method, the subject structure is reduced into a number of load points that are connected together to form finite elements. The governing equation of the motion are written is discrete forms, where displacement of each node is the unknown part of the solution. A simulation load or other external influence is applied to a system and resulting effect is analyzed.

3.8.2. Meshing of the assembly

The models were then imported to ANSYS 18 for further analysis. Meshing was done on the total assembly and fine meshing was done at the critical areas where the maximum stresses are expected. The quality o mesh was maintained by following the standard quality criteria like aspect ratio less than 5, jacobian ratio in between 0.7 to 10, warpage less than 15 and minimum angle of quad 45, maximum angle 135. Continuity between all the elements was maintained.

3.8.2.1. Fixing Table Machine

The machine table is fixed in four point shown in figure 3.13 by bolts on the ground any leg of table has four bolts figure4.8.after analyzed the leg of table machine the maximum deformation of it is less than 40 micron for each leg shown in figure 3.14 and the maximum stress and strain of it is 7.23 MPa and 32.3 micron figure 3.14. the machine leg is manufacturing from structural steel.

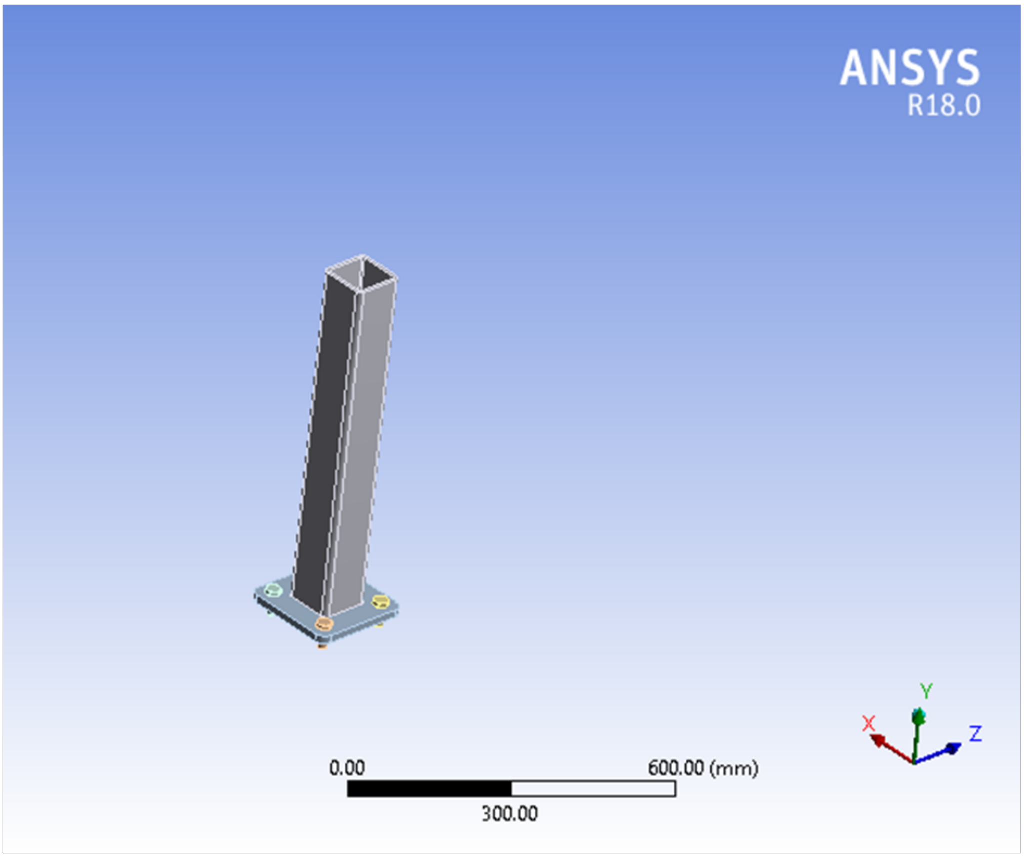

Figure 3.11.: Total Deformation

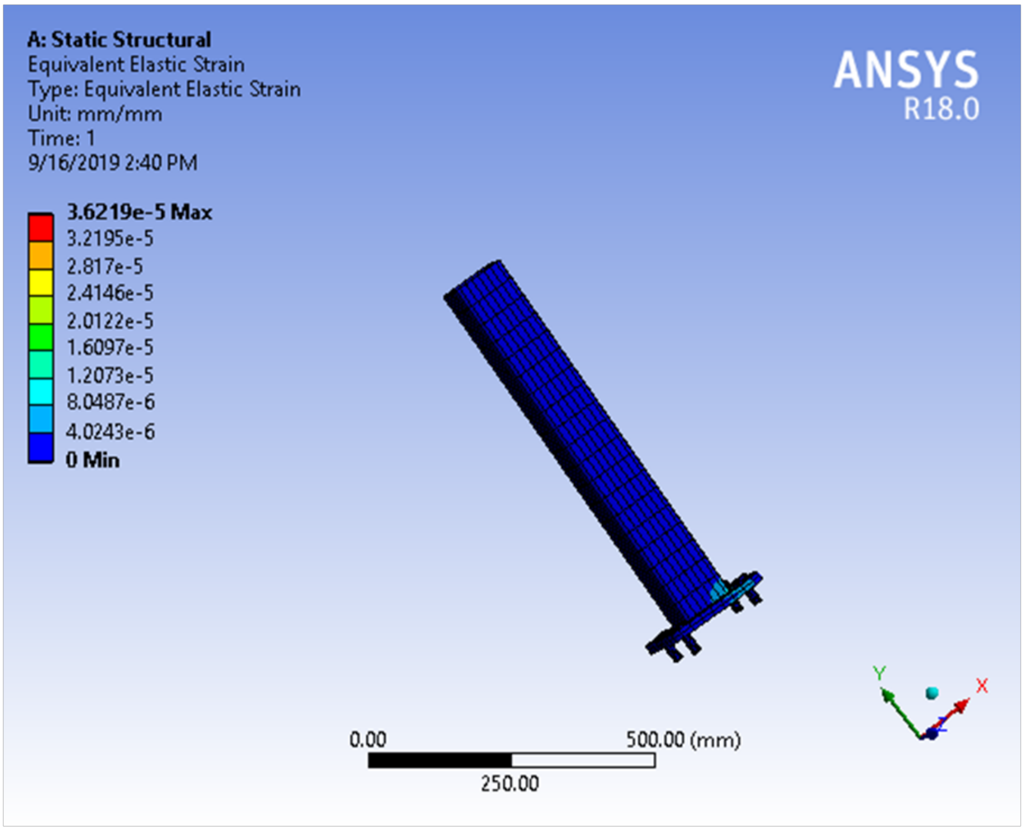

Figure 3.13.: Equivalent Elastic Strain

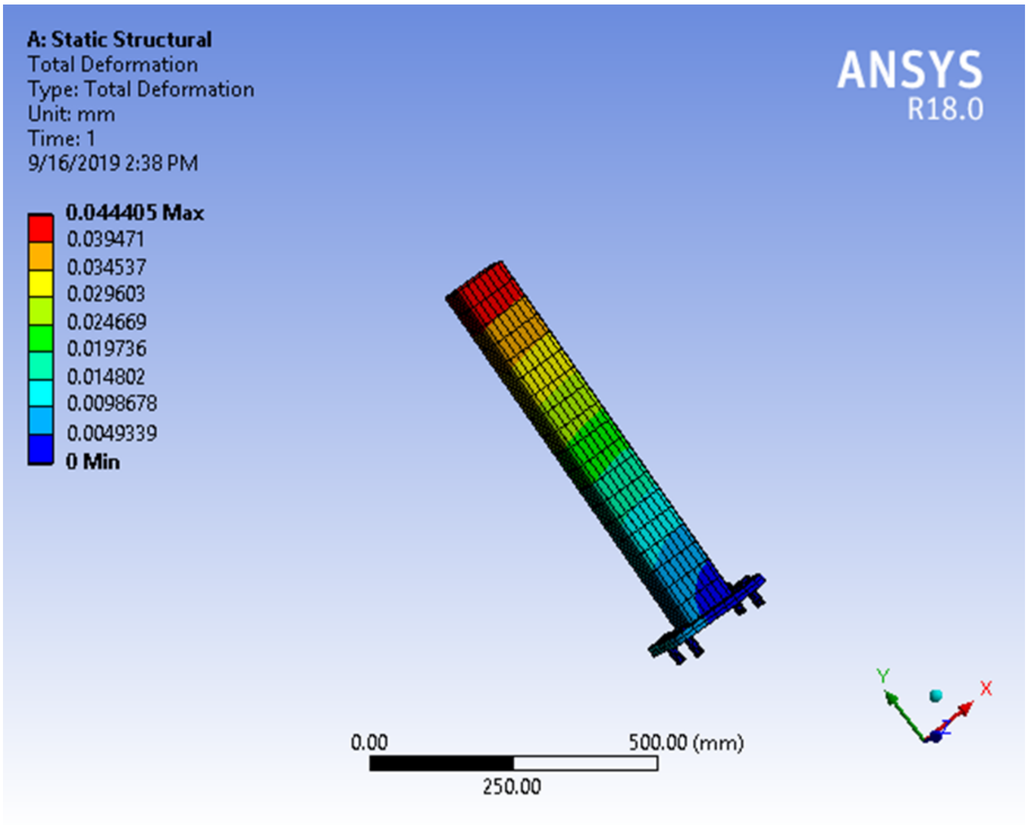

Figure 3.12.: total deformation in fixing points

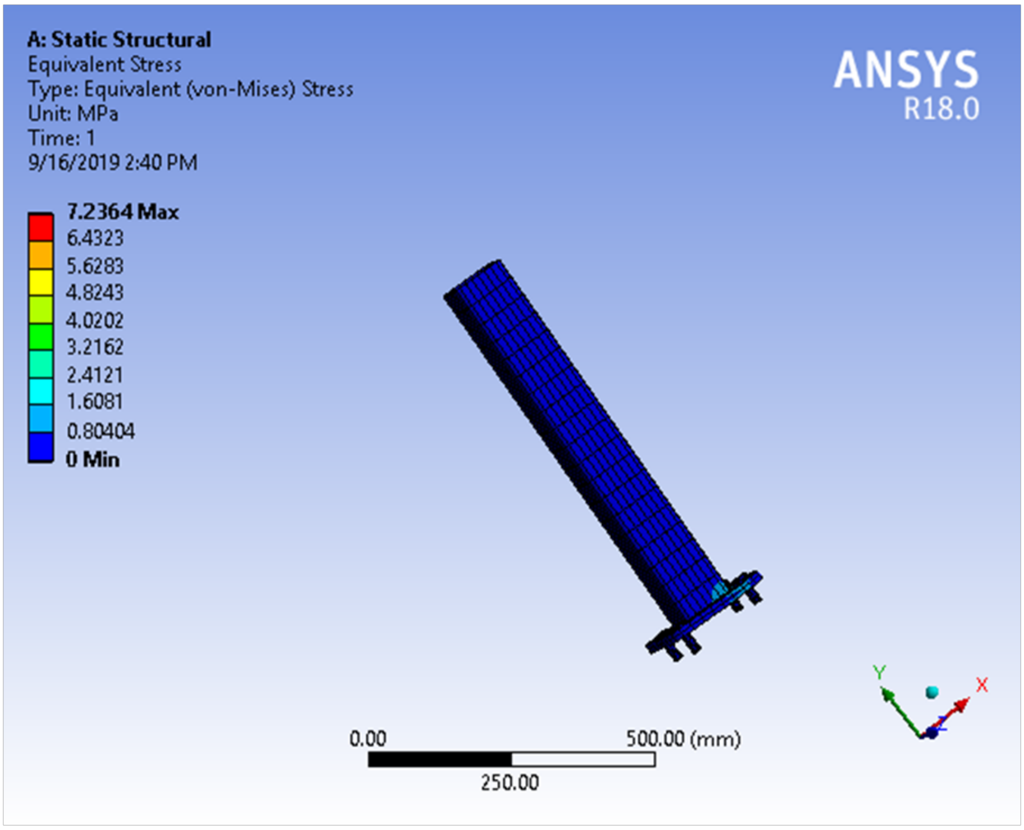

Figure 3.14.: Equivalent Stress

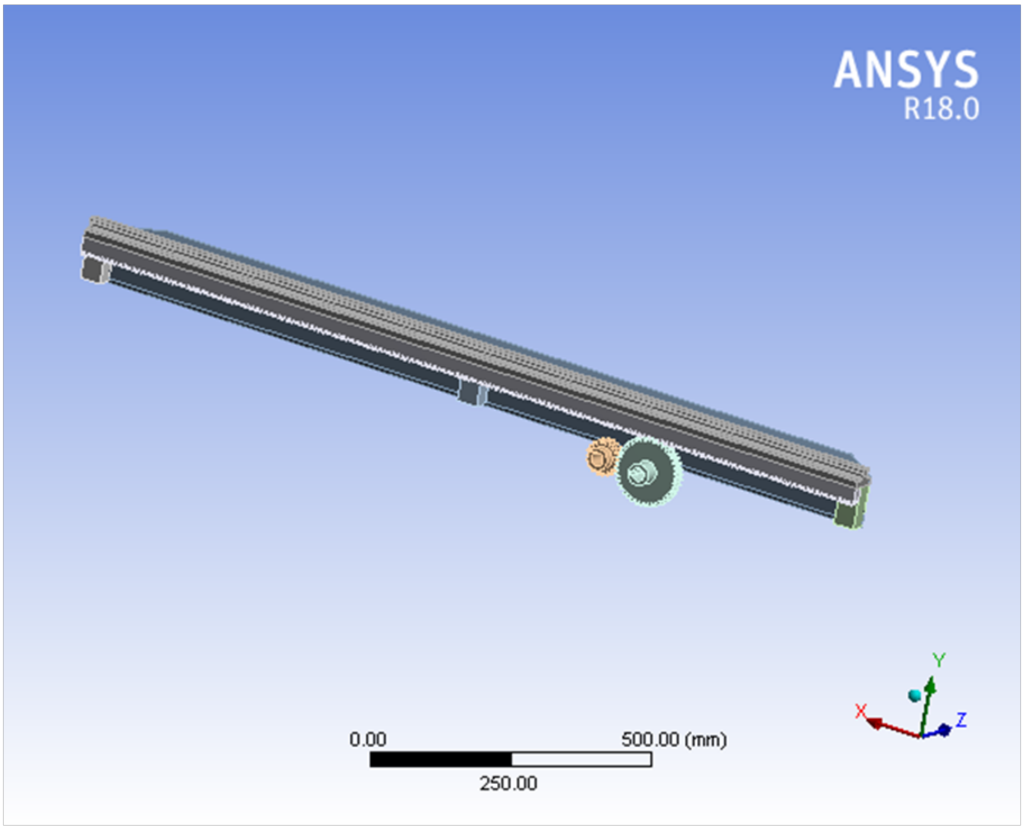

Figure 3.15.: x-axis Geometry

3.8.2.2. X-Axis analysis

X –axis slide will be the longest among all the drives which are not under any moment but comes under the direct load. Mesh is generated with 52804 elements and 24667 nodes shown in figure 3.15. The different loading conditions were required to observe the most influencing force direction which will cause maximum deflection. shown in fig 3.16.

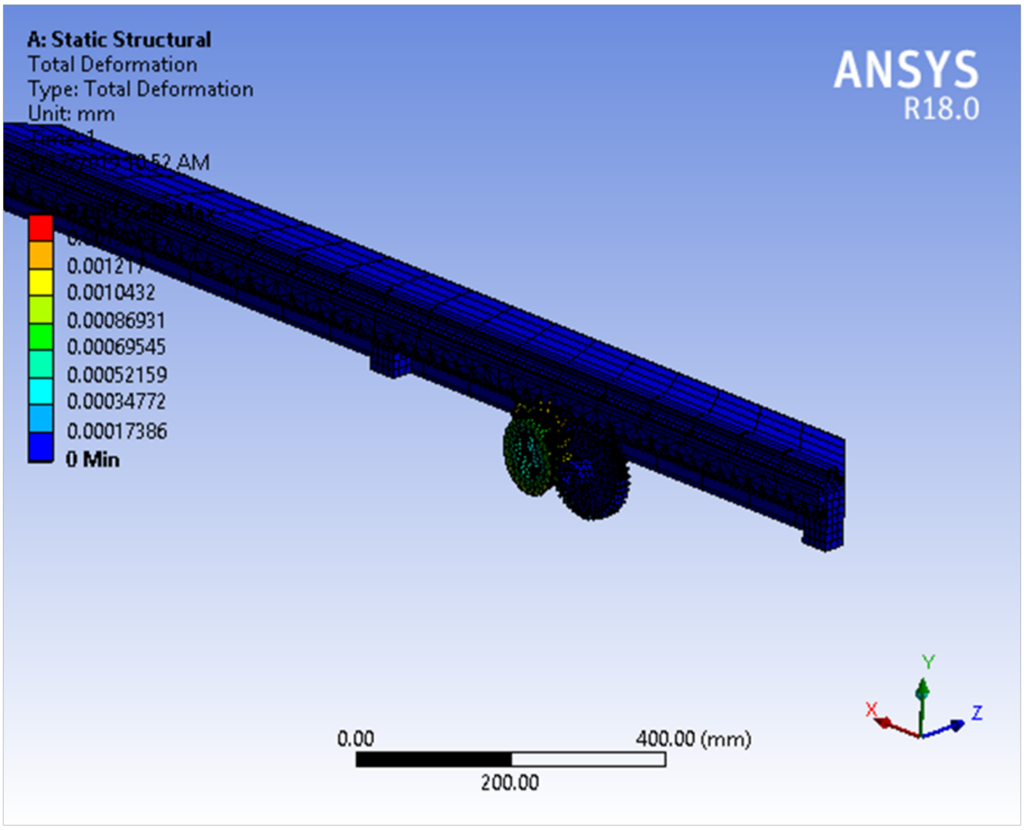

Figure 3.16.: Total Deformation

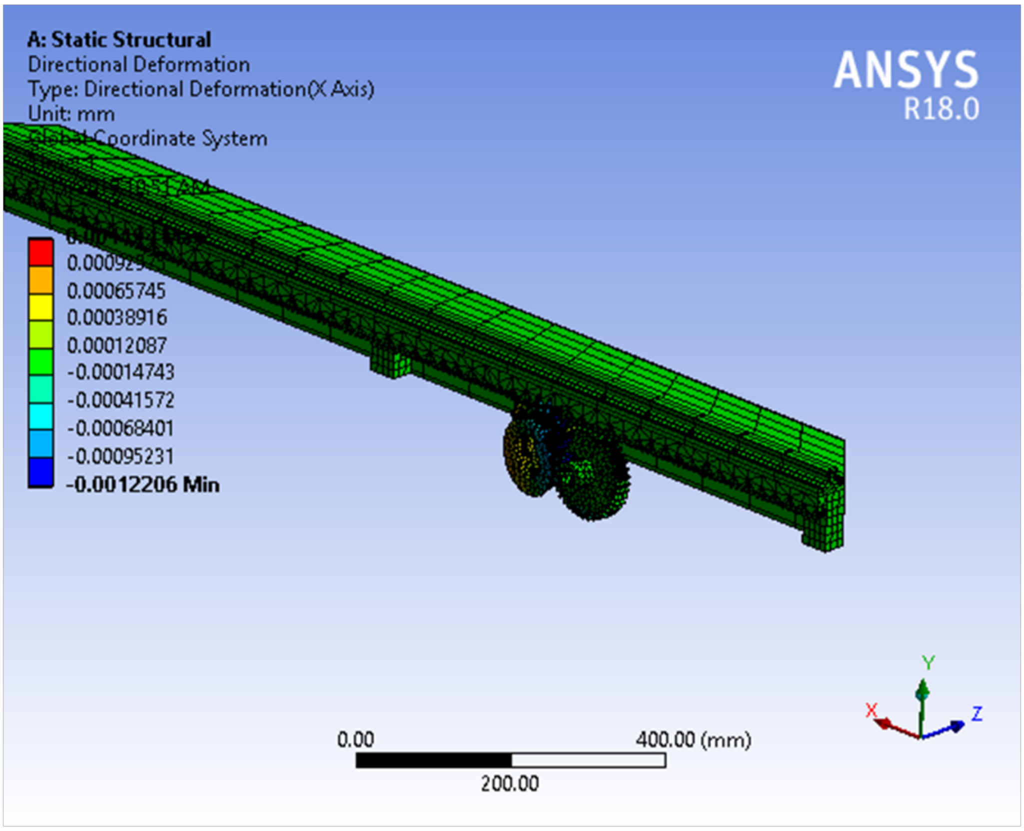

Figure 3.17.: Directional Deformation

3.8.2.3. Y-Axis analysis

Analysis is done in ANSYS by creating the FEM model of the Y-axis Drive. The CAD model can be seen in figure 3.18.The Boundary condition applied shown in figure 3.18 are giving fixed support to the both ends of the Y-axis drive. Selection of Y-axis slide is most critical in terms of deflection because it is the case of simply supported beam with large span length. The selection of the Y-axis slide is done without considering the self weight of the components whose analysis is done in ANSYS as shown in Figure 3.19 and Figure 3.20.

Mesh is generated with 58705 elements and 117718 nodes shown in figure 4.16.The different loading conditions are mention in the figure. The different loading conditions were required to observe the most influencing force direction which will cause maximum deflection as shown in Figure 3.21.

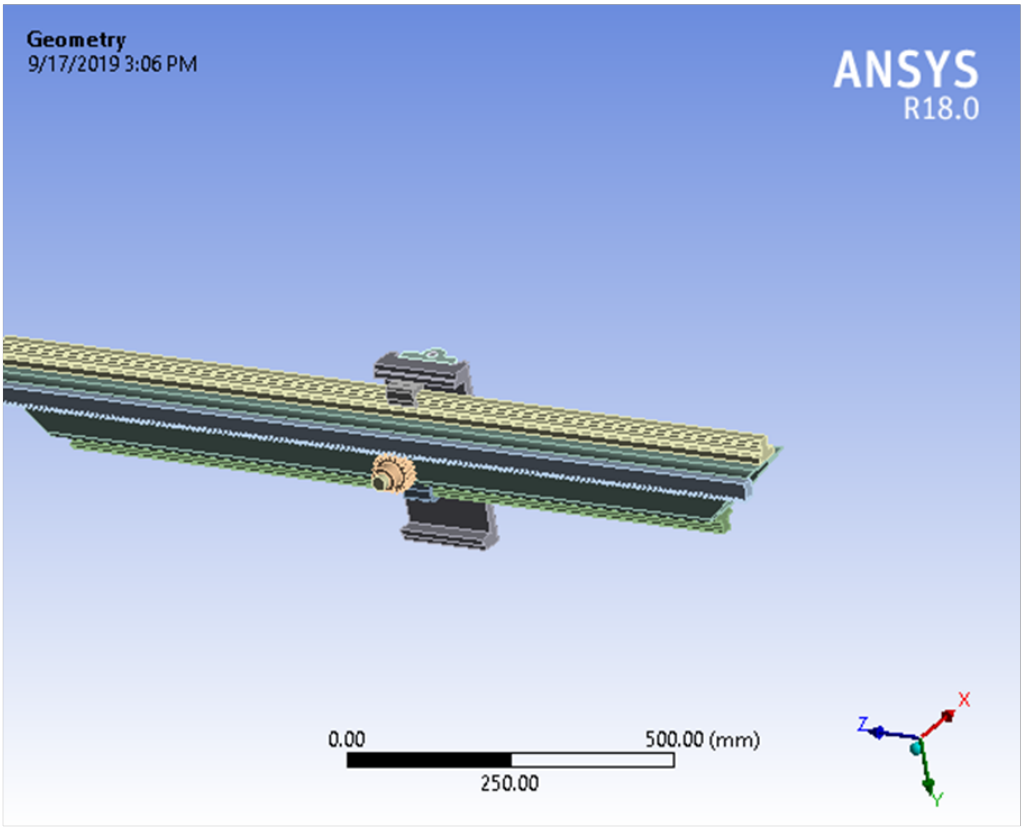

Figure 3.18.: Y-axis Geometry

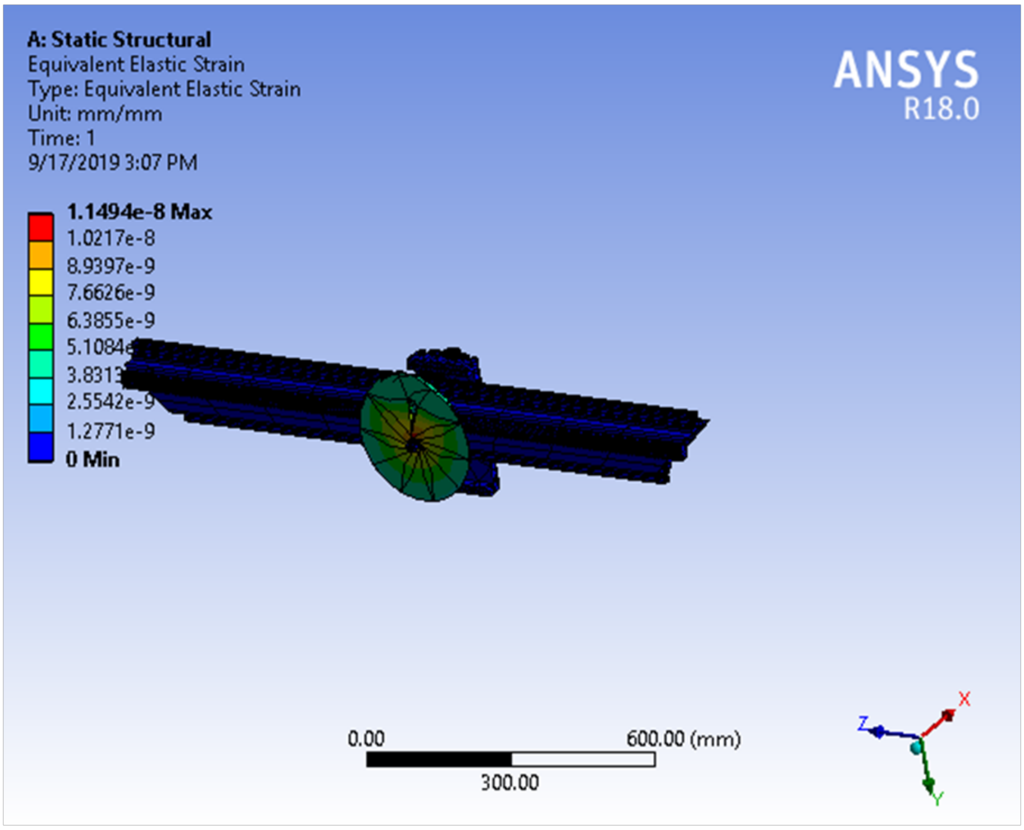

Figure 3.19.: Equivalent Elastic Strain

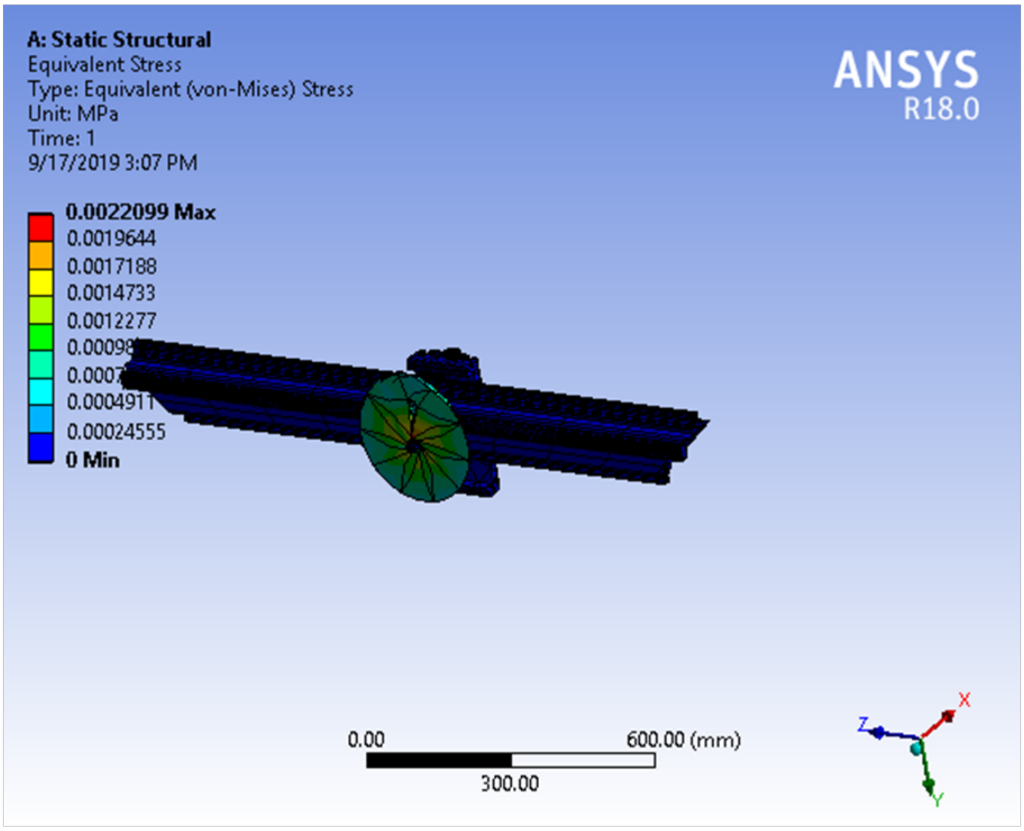

Figure 3.20.: Equivalent Stress

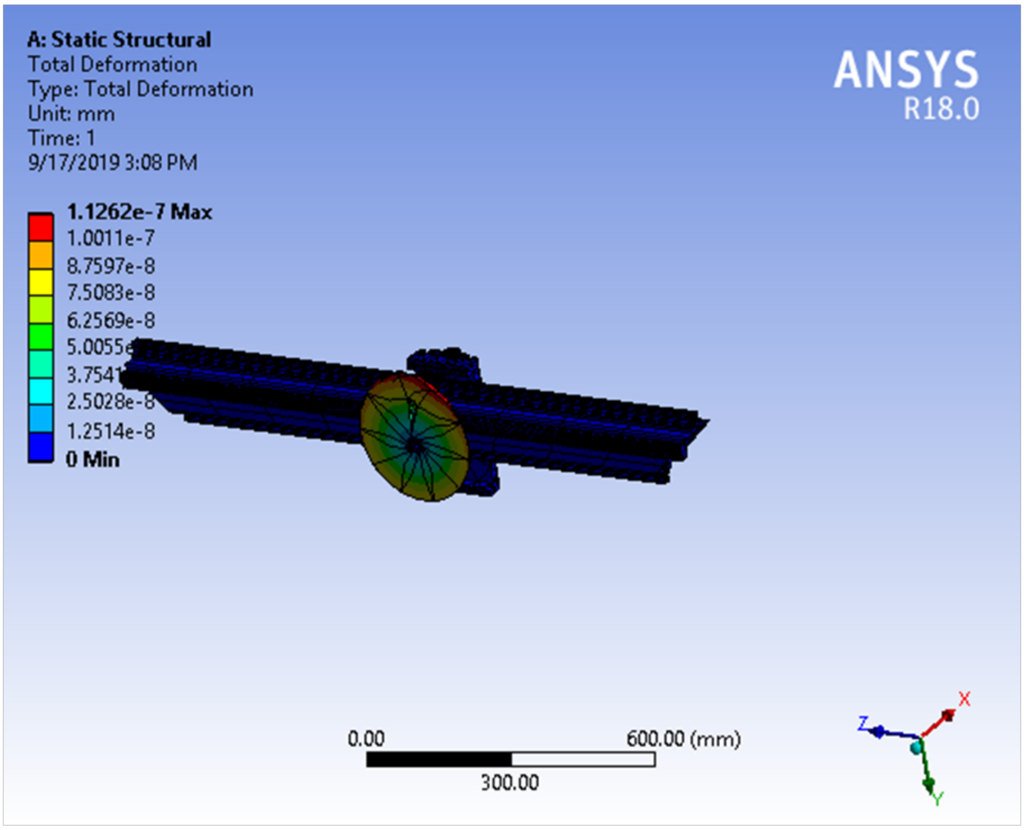

Figure 3.21.: Total Deformation

3.8.3. Conclusion of Results and Discussion

The design process followed to minimize the deflection was found to be effective as the deflection in most of the members were under 10 micron and the overall deflection in the system was reduced to 50 micron. So by proper designing method it can be further reduced by the study and selection of each component separately. Mainly the dimension of the non standard components were find out in this chapter by analysis namely bracket, back plate of Y-axis and the Side plate, where as the selection of standard components were verified.

Chapter Four
Simulations and Design Outcomes

4.1. Practical Session

The implemented samples of welding according to WPS in automatic machine by implementing next steps:

1. prepare the joint of welding: preparing the welding joint is done by welder to fixing the sample plate before put on the machine. the preparing must be straight on surface because avoid the imperfections like lack of fusion. This is shown in Figure 4.1
2. setting initial parameters of joint in sheet cam program which are get it from CAD design program and send to MACH3 to implementing. This is shown in Figure 4.2 and Figure 4.3
3. setting the parameter of welding according to WPS in welding machine as shown in Figure 4.4
4. Finally implementing of welding process. However, before the create the welding process must be do some things listed as follows.
   a) set the zero point of machine.
   b) set zero point of part .
   c) select the speed of welding torch according WPS.
   d) initiate the welding arc before the torch motion is begin. The sample after welding process fig 4.23

Figure 4.1.: Welding Preparation Joint

Figure 4.2.: SHEET CAM SOFTWARE

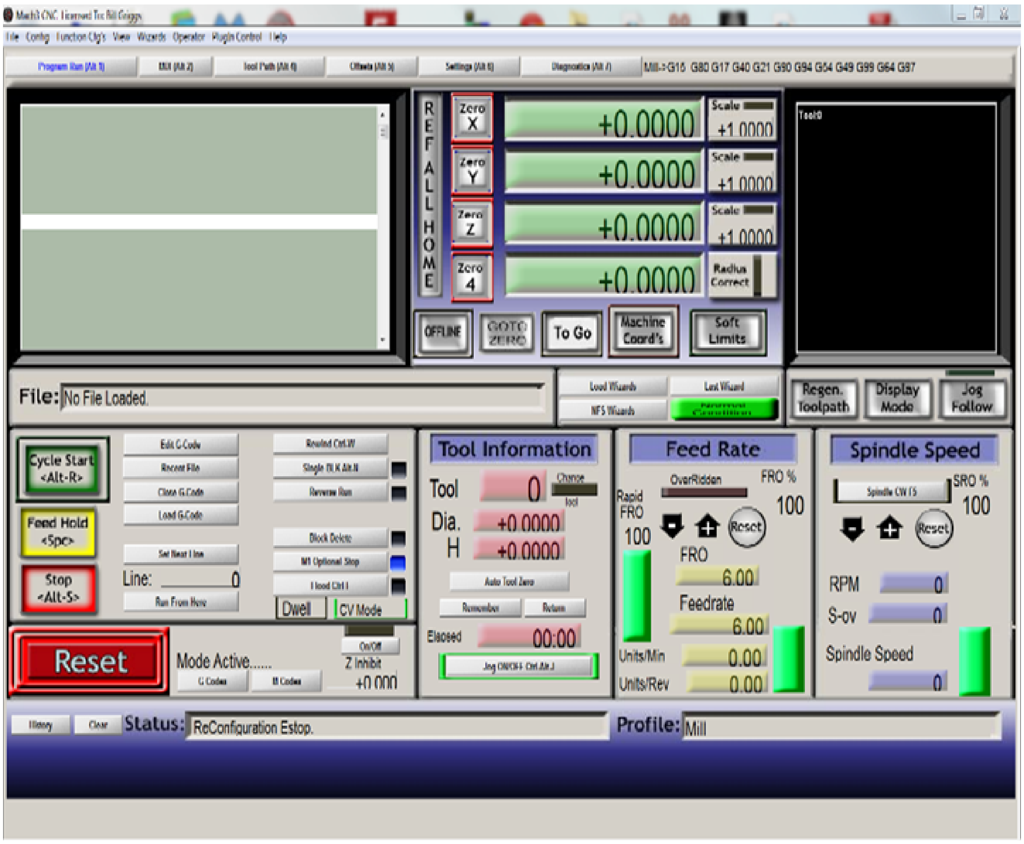

Figure 4.3.: MACH3 SOFTWARE

Figure 4.4.: Welding machine

Figure 4.5.: sample after welding

Also we were implemented sample of cladding welding in machine by same steps in figure 4.1.

Figure 4.6.: cladding welding

Chapter Five
Conclusions and Recommendations

5.1. Conclusions

The FEM analysis of the machine tool drives in chapter 4 justify the components selected through design process and optimization is done if the deflection value exceeds the allowable value. As far as possible selection of standard components are preferred for the ease of machine construction while the non standard components such as Bracket of axis are designed simple to manufactured.

Automatic welding machine was successfully designed. The design can be implemented to manufacturing working model. Knowledge of various fields of engineering such as strength of material machine design was applied to carry out efficient designing. While designing manufacturability of the design was considered. Simplicity of the design was maintained to its best in order to achieve the objective of designing cost efficient automatic welding machine.

The following conclusion can be made from the work:

Bracket designed is safe to hold the spindle and thickness is optimized.

The Z-axis drive deflection is below 5 micron and Y-axis drive is below 10 micron instead of having a long drive distance of 1405 mm.

The different shape of the side plate of joining Y-axis and X-axis is iterated and result was found satisfactory with tapered plate whose result can be further improved by increasing the width of plate.

5.2. Recommendations

The work done here was focused toward setting up the empirical relation to various machine components and finding out the design procedure. Its study has been done thoroughly and interdependency is finding out which affects each other. The Analysis part done in the ANSYS was to validate these results and moving towards the optimization but there is huge scope for the future work as follows.

- adding fixture in table machine to reduce distortion of parts.
- for Z axis need to use electrical sensor to avoid the slope on service.
- change the Mach3 software and use master-fire software because is easier.
- Considering the thermal and preload effects in table machine to improve the results.
- Cost analysis of the structure.

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