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CNC ROUTING MACHINE

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To my instructors Dr. Samer Mayaleh,
without his support and encouragement, this agonizing effort would not have been possible.

Abstract

CNC Router systems have been around for a while however, their popularity is rapidly growing in all arenas. This is probably due to the impressive capabilities of these machines. Offering the ability to create complex shapes that would take a skilled craftsman much longer.

In the past 5 years there have been an increasing number of businesses and hobbyist invests in a router system. Many people, however, are still in the dark as to what these machines do and how they work. This is where we want to help.

On this page we will discuss and explain the basics of CNC router Systems. We'll be covering topics like the parts and types of a CNC machine, how they work, the language typically associated with CNC routers.

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INTRODUCTION

A **CNC router** is a router whose tool paths can be controlled via computer numerical control. It is a computer-controlled machine for cutting various hard materials, such as wood, composites, aluminium, steel, plastics, and foams. It is one of many kinds of tools that have CNC variants. A CNC router is very similar in concept to a CNC milling machine.

CNC routers come in many configurations, from small home-style "desktop" CNC routers to large "gantry" CNC routers used in boat-making facilities. Although there are many configurations, most CNC routers have a few specific parts: a dedicated CNC controller, one or more spindle motors, AC inverters, and a table.

CNC routers are generally available in 3-axis and 5-axis CNC formats.

The CNC router is run by a computer. Coordinates are uploaded into the machine controller from a separate program. CNC router owners often have two software applications—one program to make designs (CAD) and another to translate those designs into a program of instructions for the machine (CAM). As with CNC milling machines, CNC routers can be controlled directly by manual programming, but CAD/CAM opens up wider possibilities for contouring, speeding up the programming process and in some cases creating programs whose manual programming would be, if not truly impossible, certainly commercially impractical.

CNC routers can be very useful when carrying out identical, repetitive jobs. A CNC router typically produces consistent and high-quality work and improves factory productivity.
A CNC router can reduce waste, frequency of errors, and the time the finished product takes to get to market.

A CNC router gives more flexibility to the manufacturing process. It can be used in the production of many different items, such as door carvings, interior and exterior decorations, wood panels, sign boards, wooden frames, mouldings, musical instruments, furniture, and so on. In addition, the CNC router makes thermo-forming of plastics easier by automating the trimming process. CNC routers help ensure part repeatability and sufficient factory output.

1. NUMERICAL CONTROL

Numerical control technology as it is known today emerged in the mid 20th century. It can be traced the year of 1952, the U.S Air Force, and the names of john parsons and the Massachusetts institute of technology in Cambridge, MA, USA. It was not applied in production manufacturing until the early 1960`s. the real boom came in the form on CNC, around the year of 1972, and decade later with the introduction of affordable micro computers. The history and development of this fascinating technology has been well documented in many publications.

In the manufacturing filed, and particularly in the area of metal working, Numerical Control technology has caused something of revolution. Even in the every days before computers became standard fixtures in every company and in many homes, the machine tools equipped with Numerical Control system found their special place in the machine shops. the recent evolution of micro electronics and the never ceasing computer development , including its impact on Numerical Control , has brought significant changes to the manufacturing sector in general and metalworking industry in particular.

1.1. DEFINITION OF NUMERICAL CONTROL

In various publication and articles, many descriptions have been used during the years, to define what Numerical Control is. Many of these definitions share the same idea, same basic concept, just use different wording.

The majority of all the known definitions can be summed up into relatively simple statement:

Numerical control can be defined as an operation of machine tools by the means of specifically coded instructions to the machine control system.

The instructions are combinations of the letters of alphabet, digits and selected symbols, for example, a decimal point, the percent sign or the parenthesis symbols. All instructions are written in a logical order and a predetermined form. The collection of all instructions necessary to machine a part is called an NC program, CNC program, or a part program. Such a program can be stored for a future use and used repeatedly to achieve identical machining results at any time.

- ## NC and CNC Technology

In strict adherence to the terminology, there is a difference in the meaning of the abbreviations NC and CNC. The NC stands for the order and original Numerical Control technology, whereby the abbreviation CNC stands for the newer Computerized Numerical Control technology, a modern spin-off of its older relative. However, in practice, CNC is the preferred abbreviation. To clarify the proper usage of each term, look at the major differences between the NC and the CNC systems.

Bothe systems perform the same tasks, namely manipulation of data for the purpose of machining a part. In both cases, the internal design of the control system contains the logical instructions that process the data. At this point the similarity ends.

The NC system (as opposed to the CNC system) uses fixed logical functions, those that are built-in and permanently wired within the control unit. These functions can`t be changed by the programmer or the machine operator. because of the fixed writing of the control logic, the NC control system can interpret a part program, but it does not allows any changes must be made away from the control , typically in an office environment. Also, the NC system requires the compulsory use of punched tapes for input of the program information.

The modern CNC system, but not the old NC system, uses an internal micro processor (I.e., a computer). This computer contains memory registers storing a variety of routines that are capable of manipulating logical functions. That means the part programmer or the machine operator can change the program of the control itself (at the machine), with instantaneous results. This flexibility is the greatest advantage of the CNC systems and probably the key element the contributed to such a wide use of the technology in modern manufacturing. The CNC programs and the logical functions are stored on special computer chips, as software instructions. Rather than used by the hardware connections, such as wires, that controls the logical functions. In contrast to the NC system, the CNC system is synonymous with the term `softwired`.

When describing a particular subject that relates to the numerical control technology, it is customary to use either the term NC or CNC. Keep in mind that NC can also mean CNC in everyday talk, but CNC can never refer to the order technology, described here under the abbreviation of NC. The letter `C` stands for computerized, and it is not applicable to the hardwired system. All control systems manufactured today are of the CNC design. Abbreviations such as C&C or C’n’C are not correct and reflect poorly on anybody that uses them.

1.2. CONVENTIONAL AND CNC MACHINING

What makes the CNC machining superior to the conventional methods? Is it superior at all? Where are the main benefits? If the CNC and the conventional machining processes are compared, a common general approach to machining a part will emerge:

1. Obtain and study the drawing
2. Select the most suitable machining method
3. Decide on the setup method (work holding)
4. Select the cutting tools
5. Establish speeds and feeds
6. Machine the part

The basic approach is the same for both types of machining. The major difference is in the way how various data are input. A feed rate of 10 inches per minute (10 in/min) is the same in manual or CNC applications, but the method of applying it is not. The same can be said about a coolant – it can be activated by turning a knob, pushing a switch or programming a special code. All these actions will result in a coolant rushing out of a nozzle. In both kinds of machining, a certain amount of knowledge on the part of the user is required. After all, metal working, particularly metal cutting is mainly a skill, but it is also, to a great degree, an art and a profession of large number of people. So is the application of Computerized Numerical Control. Like any skill or art or profession, mastering it to the last detail is necessary to be successful. It takes more than technical knowledge to be a CNC machinist or CNC programmer. Work experience, intuition and what is sometimes called a `gut-feel` is much needed supplement to any skill.

In conventional machining, the machine operator sets up the machine and moves each cutting tool, using one or both hands, to produce the required part. The design of a manual machine tool offers many features that help the process of machining a part-levers, handles, gears and dials, to name just a few. The same body motions are repeated by the operator for every part in the batch. However, the word `same` in this context really means `similar` rather than `identical`. Humans are not capable to repeat every process exactly the same at all times-that is the job of machines. People cannot work at the same performance level all the time, without a rest. All of us have some good and some bad moments. The results of these moments, when applied to machining a part, are difficult to predict. There will be some differences and inconsistencies within each batch of parts. The parts will not always be exactly the same. Maintaining dimensional tolerances and surface finish quality are the most typical problems in conventional machining. Individual machinists may have their fellow colleagues. Combination of these and other factors create a great amount of inconsistency.

The machining under numerical control does away with the majority of inconsistencies. It does not require the same physical involvement as machining. Numerically
Controlled machining does not need any levers or dials or handles, at least not in the same sense as conventional ma-chining does. Once the part program has been proven, it can be used any number of times over, always returning consistent results. That does not mean there are no limiting factors. The cutting tools do wear out, the material blank in one batch is not identical to the material blank in another batch, the setups may vary, etc. These factors be considered and compensated for, whenever necessary.

The emergence of the numerical control technology does not mean an instant, or even a long term, demise of all manual machines. There are times when a traditional machining method is preferable to a computerized method. For example, a simple one time job may be done more efficiently on a manual machine than a CNC machine. Certain types of machining jobs will benefit from manual or semiautomatic machining, rather than numerically controlled machining. The CNC machine tools are not meant to replace every manual machine, only to supplement them.

In many instances, the decision whether certain machining will be done on a CNC machine or not is based on the number of required parts and nothing else. Although the volume of parts machined as batch is always in important criteria, it should never be the only factor.

Consideration should also be given to the part complexity, its tolerances, the required quality of surface finish, etc. often, a single complex part will benefit from CNC machining, while fifty relatively simple parts will not.

Keep in mind that numerical control has never machined a single part by itself. Numerical control is only a process or a method that enables a machine tool to be used in a productive, accurate and consistent way.

1.3. NUMERICAL CONTROL ADVANTAGES

What are the main advantages of numerical control?
It is important to know which areas of machining will benefit from it and which are better done the conventional way. It is absurd to think that a two horse power CNC mill will win over jobs that are currently done on a twenty times more powerful manual mill. Equally unreasonable are expectations of great improvements to cutting speeds and feedrates over a conventional machine. If the machining and tooling conditions are the same, the cutting time will be very close in both cases.

Some of the major areas where the CNC user can and should expected improvement:

- Setup time reduction
- Lead time reduction
- Accuracy and repeatability
- Contouring of complex shapes
- Simplified tooling and work holding
- Consistent cutting time
- General productivity increase

Each area offers only a potential improvement. Individual users will experience different levels of actual improvement, depending on the product manufactured on-site, the CNC machine used, the setup methods, complexity of fixturing, quality of cutting tools, management philosophy and engineering design, experience level of the workforce, individuals attitudes, etc.

Setup Time Reduction

In many cases, the setup time for a CNC machine can be reduced, sometimes quite dramatically. It is important to realize that setup is manual operation, greatly dependent on the performance of CNC operator, the type of fixturing and general practices of the machine shop. Setup time is unproductive, but necessary – it is a part of the overhead costs of doing business. To keep the setup time to a minimum should be one of the primary considerations of any machine shop supervisor, programmer and operator.

Because of the design of CNC machines, the setup time should not be major problem. Modular fixturing, standard tooling, fixed locators, automatic tool changing, pallets and other advanced features, make the setup time more efficient than comparable setup of a conventional machine. With a good knowledge of modern manufacturing, productivity can be increased significantly.

The number of parts machined under one setup is also important in order to assess the cost of setup time. If a great number of parts are machined in one setup, the setup cost per part can be very insignificant. A very similar reduction can be achieved be grouping several different operations into a single setup. Even if the setup time is longer, it may be justified when compared to the time required to setup several conventional machines.

- **Lead Time Reduction**

Once a part program is written and proven, it is ready to be used again in the future, even at a short notice. Although the lead time for the first run is usually longer, it is virtually nil for any subsequent run. Even if an engineering change of the part design requires the program to be modified, it can be done usually quickly, reducing the lead time.
Long lead time, required to design and manufacture several special fixtures for conventional machines, can often be reduced by preparing a part program and the use of simplified fixturing.

- **Accuracy and Repeatability**

The high degree of accuracy and repeatability of modern CNC machines has been the single major benefit to many users. Whether the part program is stored on a disk or in the computer memory, or even on a tape (the original method), it always remains the same. Any program can be changed at will, but once proven, no changes are usually required any more. A given program can be reused as many times as needed, without losing a single bit of data it contains. True, program has to follow for such changeable factors as tool wear and operating temperatures, it has to be stored safely, but generally very little interference from the CNC programmer or operator will be required, the high accuracy of CNC machines and their repeatability allows high quality parts to be produced consistently time after time.

- **Contouring of Complex Shapes**

CNC lathes and machining centers are capable of contouring a variety of shapes. Many CNC users acquired their machines only to be able to handle complex parts. Good examples are CNC applications in the aircraft and automotive industries. The use of some form of computerized programming is virtually mandatory for any three dimensional tool path generation.

Complex shapes, such as molds, can be manufactured without the additional expense of making a model for tracing. Mirrored parts can be achieved literally at the switch of a button, templates, wooden models, and other pattern making tools.

- ## Simplified Tooling and Work Holding

No standard and homemade tooling that clutters the benches and drawers around a conventional machine can be eliminated by using standard tooling, specially designed for numerical control applications. Multi-step tools such as pilot drills, step drills, combination tools, counter borers and others are replaced with several individual standard tools. These tools are often cheaper and easier to replace than special and nonstandard tools. Cost-cutting measures have forced many tool suppliers to keep a low or even a nonexistent. Standard, off-the shelf tooling can usually be obtained faster than nonstandard tooling.

Fixturing and work holding for CNC machines have only one major purpose – to hold the part rigidly and in the same position for all parts within a batch. Fixtures designed for CNC work do not normally require jigs, pilot holes and other hole locating aids.

- ## Cutting Time and Productivity Increase

The cutting time on the CNC machine is commonly known as the cycle time- and is always consistent. Unlike a conventional machining, where the operators skill, experience and personal fatigue are subject to changes, the CNC machining is under the control of a computer. The small amount of manual work is restricted to the setup and loading and unloading the part. For large batch runs, the high cost of the unproductive time is spread among many parts, making it less significant. The main benefit of a consistent cutting time is for repetitive jobs, where the production scheduling and work allocation to individual machine tools can be done very accurately.

The main reason companies often purchase CNC machines is strictly economic – it is a serious investment. Also, having a competitive edge is always on the mind of every plant manager. The numerical control technology offers excellent means to achieve a significant improvement in the manufacturing productivity and increasing the overall quality of the manufactured parts. Like any means, it has to be used wisely and knowledgeably. When more and more companies use the CNC technology, just having a CNC machine does not offer the extra edge anymore. The companies that get forward are those who know to use the technology efficiently and practice it to be competitive in the global economy.

To reach the goal of major increase in productivity, it is essential that users understand the fundamental principles on which CNC technology is based. These principles take many forms, for example, understanding the electronic circuitry, complex ladders diagrams, computer logic, metrology, machine design, machine principles and practices and many others. Each one has to be studied and mastered by the person in charge. In this handbook, the emphasis is on the topics that relate directly to the CNC programming and understanding the most common CNC machine tools, the machining centers and the lathes (sometimes also called the turning centers). The part quality consideration should be very important to every programmer and machine tool operator and this goal is also reflected in the handbook approach as well as in numerous examples.

1.4. TYPES OF CNC MACHINE TOOLS

Different kinds of CNC machines cover an extremely large variety. Their numbers are rapidly increasing, as the technology development advances. It is impossible to identify all the applications; they would make a long list. Here is a brief list of some of the groups CNC machines can be part of:

- Mills and machining centres
- Lathes and turning centres
- Drilling machines
- Boring mills and profilers
- EDM machines
- Punch presses and shears
- Flame cutting machines
- Routers
- Water jet and laser profilers
- Cylindrical grinders
- Welding machines
- Benders, winding and spinning machines, etc.

CNC machining centres and lathes dominate the number of installations in industry. These two groups share the market just about equally. Some industries may give a higher need for one group of machines, depending on their needs. One must remember that there are many different kinds of lathes and equally many different kinds of ma-chining centres. However, the programming process for a vertical machine is similar to the one for a horizontal ma-chine or a simple CNC mill. Even between different ma-chine groups, there is a great amount of general applications and the programming process is generally the same For example, a contour milled with an end mill has a lot in common with a contour cut with a wire.

▪ Mills and Machining Centres

Standard number of axes on a milling machine is three-the X, Y and Z axes. The part set on a milling system is al-cutting tool rotates, it can move up and down (or in and out), but it does not physically follow the tool path.
CNC mills - sometimes called CNC milling machines - are usually small, simple machines, without a tool changer or other automatic features. Their power rating is often quite low. In industry, they are used tool room work, maintenance purposes, or small part production. They are usually designed for contouring, unlike CNC drills.
CNC machining centres are for more popular and efficient that drills and mills, mainly for their flexibility. The main benefit user gets out of a CNC machining centre is the ability to group

several diverse operations into a single setup. For example, drilling, boring, counter boring, tapping, spot facing and contour milling can be incorporated into a single CNC program. In addition, the flexibility is enhanced by automatic tool changing using pallets to minimize idle time, indexing to a different side of the part, using a rotary movement of additional axes, and a number of other features, CNC machining centres can be equipped with special software that controls the speeds and feeds, the life of the cutting tool, automatic in-process gauging and offset adjustment and other production enhancing and time saving devices.

There are two basic designs of a typical CNC machining centre. There are the vertical and the horizontal machining centres. The major difference between the two types is the nature of work that can be done on them efficiently. For a vertical CNC machining centre, the most suitable type of work are flat parts, either mounted to the fixture on the table, or help in a vise or a chuck. The work that requires machining on two or more faces in a single setup is more desirable to be done on a CNC horizontal machining centre. A good example is pump housing and other cubic-like shapes. Some multi-face machining of small parts can also be done on a CNC vertical machining center equipped with a rotary table.

The programming process is the same for both designs, but an additional axis (usually a B axis) is added to the horizontal design. This axis is either a simple positioning axis (indexing axis) for the table, or a fully rotary axis for simultaneous contouring.

This handbook concentrates on the CNC vertical machining centres applications, with a special section dealing with the horizontal setup and machining. The programming methods are also applicable to the small CNC mills or drilling and/or tapping machines, but the programmer has to conceder their restrictions.

▪ Lathes and Turning Centres

A CNC lathe is usually a machine tool with two axes, the vertical X axis and the horizontal Z axis. The main future of the lathe that distinguishes it from a mill is that the part is rotating about the machine center line. In addition, the cutting tool is normally stationary, mounted in a sliding turret. The cutting tool follows the contour of the programmed tool path. For the CNC lathe with a milling attachment, so called live tooling, the milling tool has its own motor and rotates while the spindle is stationary.

The modern lathe design can be horizontal or vertical. Horizontal type is far more common than the vertical type, but both designs exist for either group. For example, a typical CNC lathe of the horizontal group can be designed with a flat bed or a slant bed, as a bar type, chucker type or universal type. Added to these combinations or many accessories that make a CNC lathe is an extremely flexible machine tool. Typically, accessories such as a tailstock, steady rests or follow-up rests, part catchers, pullout-fingers and even a third axis milling attachment are popular components of the CNC lathe. A CNC lathe can be very versatile so versatile in fact, that it is often called a CNC turning centre. All text and program examples in this handbook use the more traditional term CNC lathe, yet still recognizing all its modern functions.

1.5. PERSONNEL FOR CNC

Computers and machine tools have no intelligence. They cannot think, they cannot evaluate a station in a rational way. Only people with certain skills and knowledge can do that. In the field of numerical control, the skills are usually in the hands of two key people- one doing the programming, the other doing the machining. Their respective numbers and duties typically depend on the company preference, its size, as well as the product manufactured there. However, each position is a quite distinct, although many companies combine the two functions into a one, often called a CNC programmer/operator.

- **CNC Programmer**

The CNC programmer is usually the person who has the most responsible in the CNC machine shop. This person is often responsible for the success of numerical control technology in the plant. Equally this person is held responsible for problems related to the CNC operations. Although duties may vary, the programmer is also responsible for a variety of tasks relating to the effective usage of the CNC machines. In fact, this person is often accountable for the production and quality of all CNC operations.
Many CNC programmers are experienced machinists, who have had a practical, hands-on experience as machine tool operations they know how to read technical drawings and they can comprehend the engineering intent behind the design. This practical experience is the foundation for the ability to 'machine' a part in an office environment. A good CNC programmer must be able to visualize all the tool motions and recognize all restricting factories that may be involved. The programmer must be able to collect, analyze process and logically integrate all the collected data into a signal, cohesive program. In simple terms, the CNC programmer must be able to decide upon the best manufacturing methodology in all respects.

In addition to the machining skills, the CNC programmer has to have an understanding of mathematical principles, mainly application of equations, solutions of arcs and angles. Equally important is the knowledge of trigonometry. Even with computerized programming, the knowledge of manual programming methods is absolutely essential to the through understanding of the computer output and the control of this output.

The last important quality of a truly professional CNC programmer is his or her ability to listen to the other people – the engineers, the CNC operators, the managers. Good listing skills are the first prerequisites to become flexible. A good CNC programmer must be flexible in order to offer high programming quality.

- **CNC Machine Operator**

The CNC machine tool operator is a complementary position to the CNC programmer. The programmer and the operator may exist in a single person, as is the case in many small shops. Although the majority of duties performed by conventional machine operator has been transferred to the CNC program, the CNC operator has many unique responsibilities. In typical cases, the operator is responsible for the tool and machine setup, for the changing of the parts, often even for some in-process inspection. Many companies expect quality control at the machine – and the operator of any machine tool, manual or computerized, is also responsible for the quality of the work done on that machine. One of the very important responsibilities of the CNC machine operator is to report findings about each program to the programmer. Even with the best knowledge, skills, attitudes and intentions, the "final" program can always be improved. The CNC operator being the one, who is the closest to the actual machining, knows precisely what extent such improvements can be.

1.6. SAFETY RELATED TO CNC WORK

One the wall of many companies is a safety poster with a simple, yet powerful message:

The first rule of safety is to follow all safety rules.

The heading of this section does not indicate whether the safety is oriented at the programming or the machining level. The season is that the safety is totally independent. It stands on its own and it governs behaviour of everybody in a machine shop and outside of it. At first sight, it may appear that safety is something related to the machining and the machine operation, perhaps to the setup as well. That is definitely true but hardly presents a complete picture.
Safety is the most important element in programming, setup, machining, tooling, fixturing, inspection, chipping, and-you-name it operation within a typical machine shop daily work. Safety can never be overemphasized. Companies talk about safety, conduct safety meeting, display posters, make speeches, call experts. This mass of information and instructions is presented to all of us for some very good reasons. Quite a few are passed on past tragic occurrences – many laws, rules and regulations have been written as a result of inquests and inquire into serious accidence.

At first sight, it may seem that in CNC work, the safety is a secondary issue. There is a lot of automation; a part program that runs over and over again, tooling that has been used in the past, a simple setup, etc. All this can lead to complacency and false assumption that safety is taken care of. This is a view that can have serious consequences.

Safety is a large subject but a few points that relate to the CNC work are important. Every machinist should know the hazards of mechanical and electrical devices. The first step towards a safe work place is with a clean work area, where no chips, oil spills and other debris are allowed to accumulate on the floor. Taking care of personal safety is equally important. Loose clothing, jewellery, ties, scarves, unprotected long hair, improper use of gloves and similar infraction, is dangerous in machining environment. Protection of eyes, ears, hands and feet is strongly recommended.

While a machine is operating, protective devices should be in place and no moving parts should be exposed. Special care should be taken around rotating spindles and automatic tool changers. Other devices that could pose a hazard are pallet changers, chip conveyors, high voltage areas, hoists, etc. disconnecting any interlocks or other safety features is dangers – and also illegal, without appropriate skills and authorization.

In programming, observation of safety rules is also important. A tool motion can be programmed in many ways. Speeds and feeds have to be realistic, not just mathematically “correct”. Depth of cut, width of cut, the tool characteristics, all have a profound effect on overall safety.
All these ideas are just a very short summery and a reminder that safety should always be taken seriously.

2. IMPORTANCE OF CNC MACHINES IN PALESTINE

We can summarize the importance of CNC machines in Palestine by the following points:

- The high cost of importing CNC machines from outside of Palestine.
- Lack of skilled operators to deal with CNC machines in addition to the high cost of training technicians outside Palestine.
- Unavailability of agents authorized to carry out maintenance and supply of spare parts for maintenance of CNC machines as well as the high cost of recruiting foreign technicians to do the necessary maintenance work.
- Customs and security restrictions imposed by the Israeli authorities in the face of import of CNC machines, spare parts and other industries related to the CNC field.
- Lack of development of the field of CNC in Palestine constitutes an obstacle to industrial progress in Palestine. For this reason, there isn't a possibility to manufacture mechanical parts and production lines on a high level of quality.
- Log of CNC machines in the timber industry and home furnishings and other would raise the quality of national products and make a possibility to export it to the outside.

3. CNC ROUTING MACHINE

This project is about 3D CNC Routing machine with 3axis. It will has mechanical structure have the capability to move in the three axis which are X, Y, and Z axis. Driving the spindle in these axis will cause the working piece to be routed. There will be an electronics attached to the structure to drive it. These electronics will handle the electrical signals came from the numerical controller (computer) to drive the structure. More detail will be discussed next.

3.1.ROUTING MACHINE MECHANICAL STRUCTURE

The mechanical structure will carry all the components of the machine. See figure 3-1.

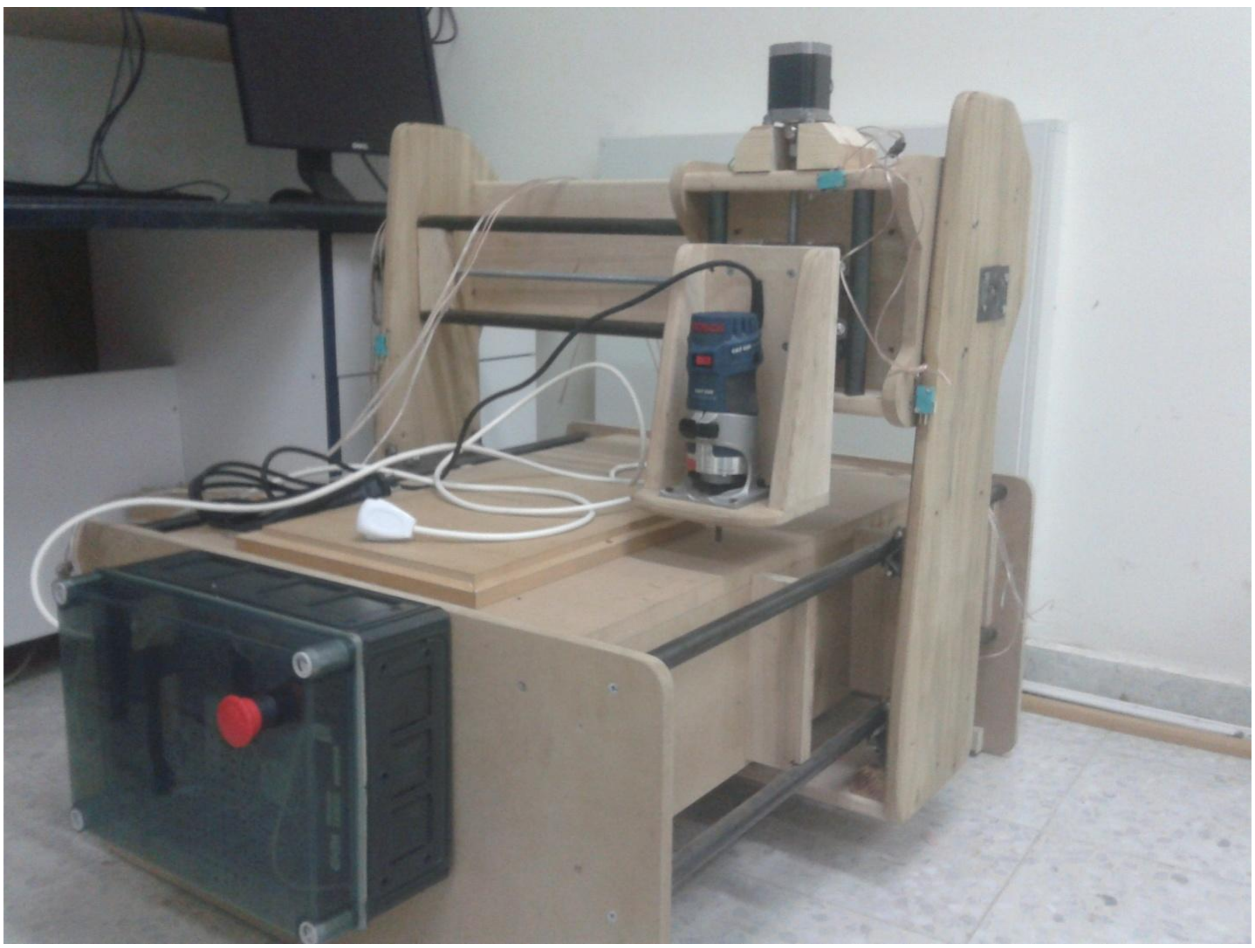


Figure 3- 1 Mechanical structure of the CNC routing machine.

This structure will have the ability to move in the three direction X,Y and Z axis. The element that will be responsible of routing the wooden piece is the spindle motor. This motor will be installed on the Z-axis of the machine. Z-axis movement will done by a power screw attached to a stepper motor. That power screw will convert the rotational movement of the stepper motor into linear movement toward the (+) Z or (-) Z-axis depending on the direction of stepper motor rotation. The Z-axis will be installed on the Y-axis of the machine on this case, the hole structure of the Z-axis will move along the Y-axis. The Z-axis structure will be connected to a power screw which will be attached to another stepper motor.

Figure 3- 2 Spindle motor installed on the Z axis of the machine.

At the same way, the hall structure of the Y-axis will move along the X-axis. So we installed a power screw and attached a third stepper motor to it.

At the end, the mechanical structure is ready to be moved in the three axis. The movement of the structure will be in response to the rotational movement of the stepper motors and screws attached to it. The displacement of each axis depends on the lead value of the screw we used. Lead value are simply the amount of axial travel that the nut will experience during one single rotation of the screw shaft.

Figure 3- 3 Y axis of the machine carrying the Z axis structure.

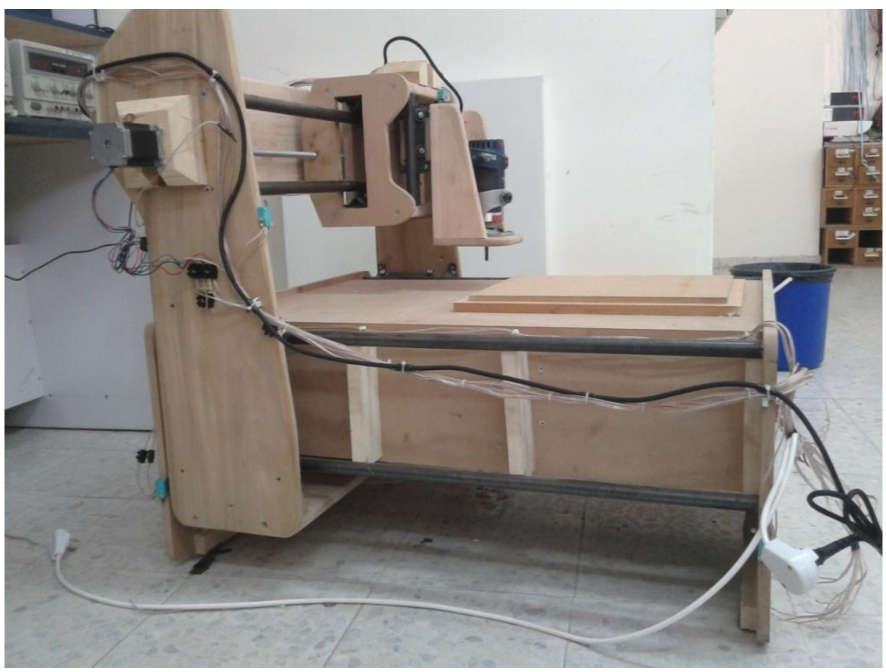


Figure 3- 4 Side view showing X axis of the machine.

3.2.ROUTING MACHINE ELECTRONICS

The electronics in general will be stepper motors to drive the structure, limit switches attached to each axis, and drive circuit to drive the machine.

The drive circuit will contain an integrated circuits to drive the stepper motors, opto-couplers to isolate the numerical controller from the drive circuit, and other components. Also there will be a relay circuit to turn on and off the spindle. In addition to the power supply which will provide the required electric power to run all the electronics in the project.

These all component will be discussed next in detail.

- **Stepper Motors**

The stepper motors, as we say previously in the mechanical structure, will be attached to the power screw of each axis. We used a bipolar stepper motor, shown in figure 3-5.

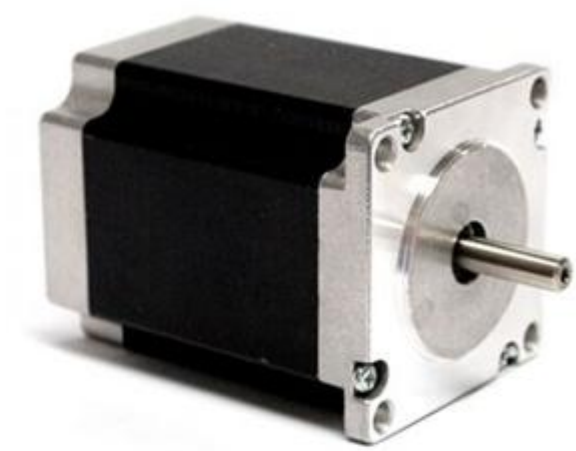


Figure 3- 5 Bipolar stepper motor.

Bi-polar two phase stepper motors have one winding per phase. A Bi- polar driver must rapidly reverse the current through the windings to change polarity. We decided to drive the stepper motor in dual coil full step mode. The method of stepping the motor energizes both phases constantly to achieve full rated torque at all positions of the motor, see figure 3-6.

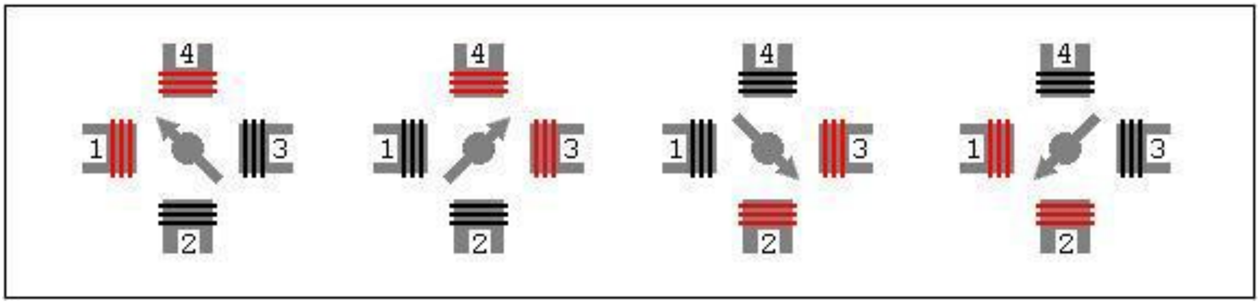


Figure 3- 6 Dual coil full step mode.

- ## Limit Switch and Home Switch

Limit switches are used to prevent any linear axis from moving too far and causing damage to the structure of the machine. You can run a machine without them, but the slightest mistake in setting up or programming can cause a lot of expensive damage.

An axis may also have a home switch. Mach3 can be commanded to move one (or all) axes to the Home position. This needs to be done whenever the system is switched on so that it knows where the axes are currently positioned. If you do not provide Home switches, then you will have to jog the axes by eye to a reference position. The Home switch for an axis can be at any coordinate position, and you define this location. Thus, the Home switches do not have to be at Machine Zero.

The repeatability of the operating point, particularly with mechanical switches, is very dependent on the quality of the switch and the rigidity of its mounting and actuating lever.

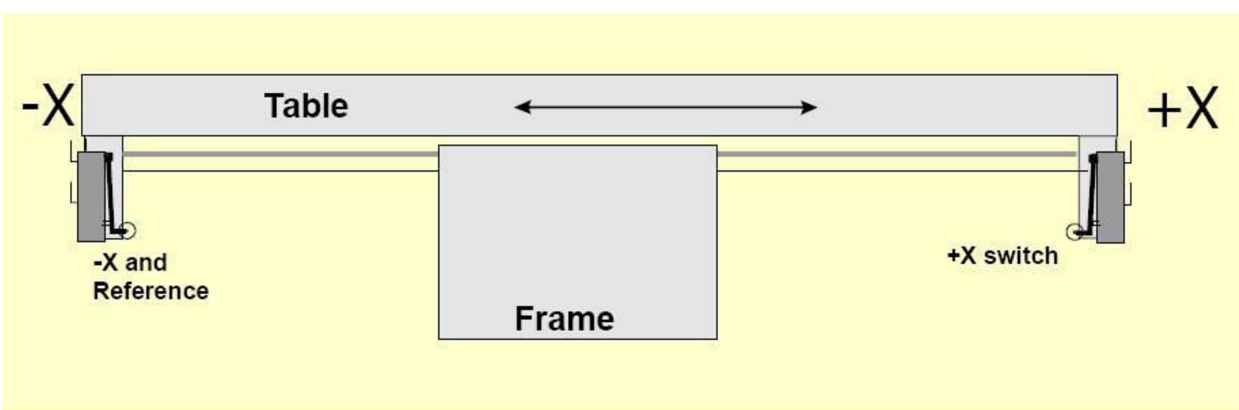


Figure 3- 7 Two switches operated by frame with over travel prevented by mechanical stops.

▪ Emergency Bush Button

We installed an E-stop bottom to send error signal to the computer which connected to the control panel to stop the machine in case an Error happened to the machine, see figure 3-8.

Figure 3- 8 Emergency stop button.

▪ Opto Couplers

Opto couplers are small optical switches that isolate circuits to prevent an electrical short from the drive circuit affecting the computer, see figure 3-9.

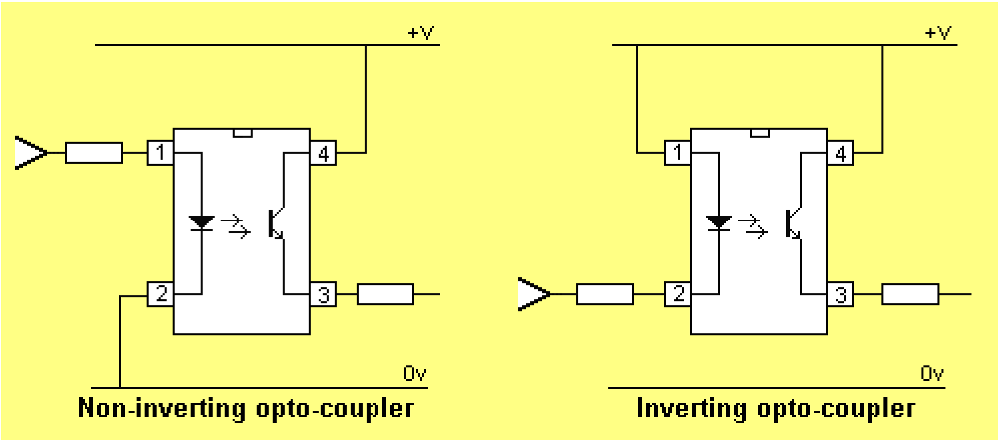


Figure 3- 9 Opto-Couplers.

These opto-couplers will be installed between the signals coming from the computer and the integrated circuits that will handle these signals. Also to isolate the computer from the feedback signals coming from the limit switches and the Emergency stop button.

- ## L298 Dual Full H-Bridge Driver

The L298 is an integrated monolithic circuit in a 15-lead multi watt package. It is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. Two enable inputs are provided to enable or disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of an external sensing resistor. An additional supply input is provided so that the logic works at a lower voltage.

- ## L297 Stepper Motor Controller IC

The L297 Stepper Motor Controller IC generates four phase drive signals for two phase bipolar and four phase unipolar step motors in microcomputer controlled applications. The motor can be driven in half step, normal and wave drive modes and on chip PWM chopper circuits permit switch-mode control of the current in the windings. A feature of this device is that it requires only clock, direction and mode input signals. Since the phase are generated internally the burden on the microprocessor, and the programmer, is greatly reduced. Mounted in DIP20 and SO20 packages, the L297 can be used with monolithic bridge drives such as the L298N or L293E, or with discrete transistors and darlingtons.

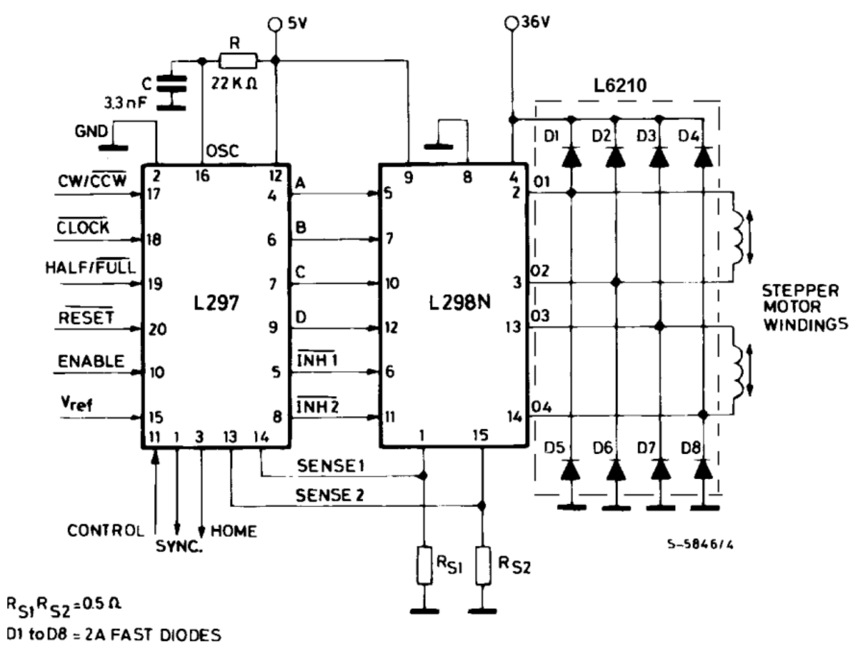


Figure 3- 10 Two phase bipolar stepper motor control circuit.

- **Power Supply**

We installed a readymade power supply to the control panel. This power supply will provide two levels of voltages to the control panel. Positive 5 volt for the integrated circuits installed in the drive circuit and positive 12 volt to provide enough power to drive the stepper motors.

3.3.DRIVE CIRCUIT

The drive circuit will contain all the components shown previously. One of the main function of this drive circuit is to drive the stepper motors attached to each axis. Drive circuit will take movement instruction from the numerical controller (computer) through the parallel port. these instructions are two signals. One for number of steps. And the other for direction of rotation. Signals coming from the parallel port will be optically isolated from the drive circuit. Now we get to the block diagram shows the relations between the components in a single axis driving module. See figure 3-11 .

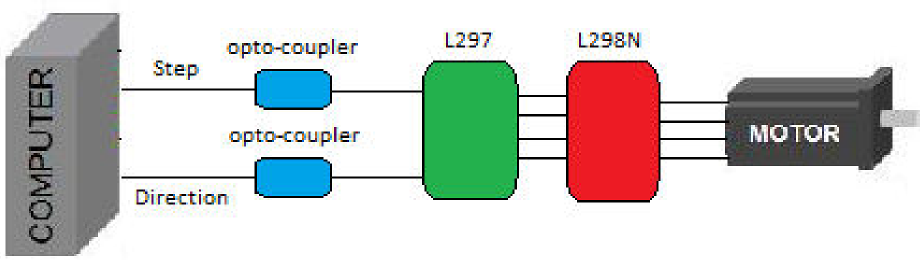


Figure 3- 11 Driving module block diagram.

This module will be repeated for the other two axis driving modules.

Another function that the drive circuit should do is to pass feedback signals coming from the limit switches and the E-Stop button to the computer through the parallel port. Also feedback signals will be optically isolated to protect the computer hard ware.

This leads us to design the drive circuit to meet the requirement of driving the machine. Using Eagle software, we designed the schematic of the drive circuit and we had the following schematic shown in figure 3-12.

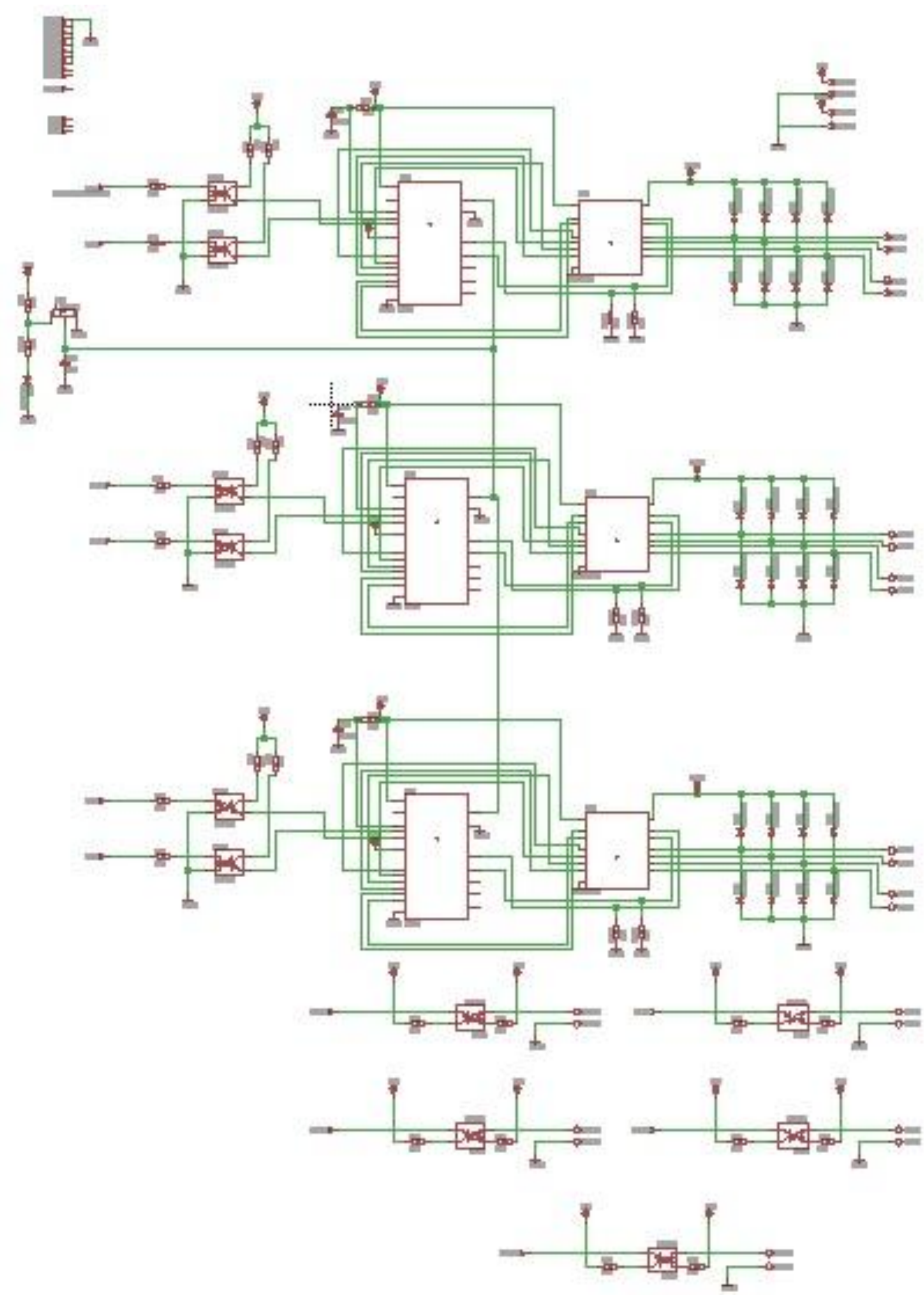


Figure 3- 12 Schematic of driving circuit.

Next step was to design the PCB layout according to the schematic shown above. The PCB layout of drive circuit is ready for implementation. See figure 3-13.

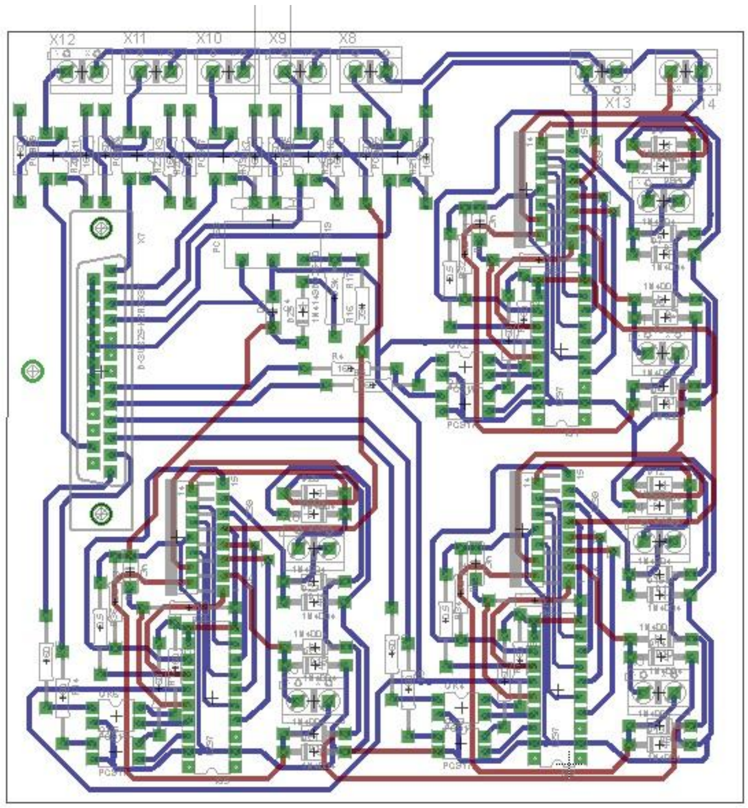


Figure 3- 13 PCB layout of driving circuit.

The drive circuit after installed all the component on it is shown in figure 3-14.

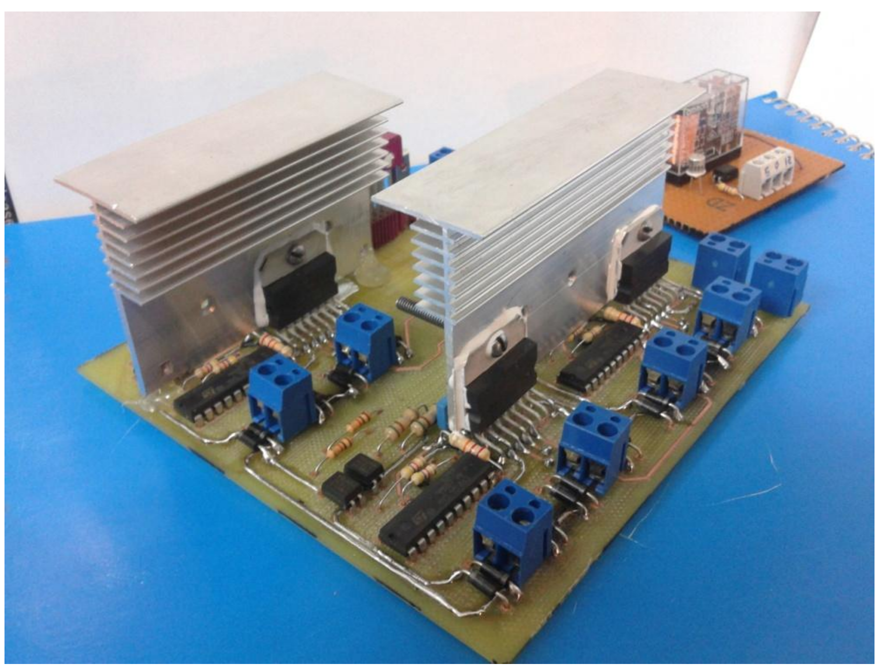


Figure 3- 14 Drive circuit.

3.4.Relay Circuit

Relay circuit is a simple circuit containing a relay to turn on and off the spindle on the machine. Relay coil will be energized by a normal NPN transistor (2N2222). Enable signal - coming to the transistor from the parallel port of the computer - is also optically isolated for protection reasons. The following schematic below describes how the relay circuit is connected. See figure 3-15.

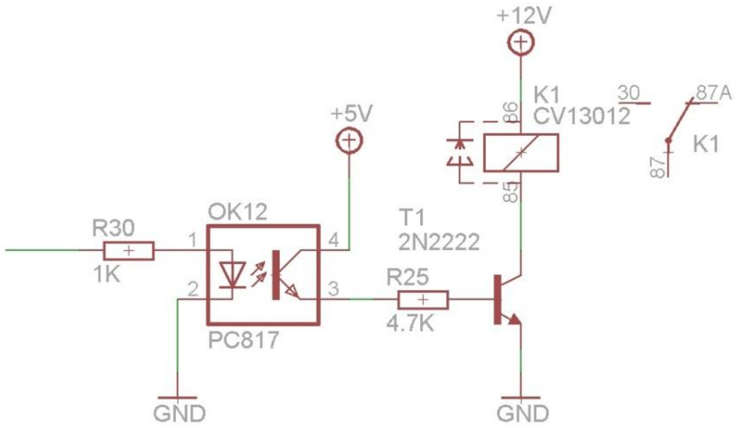


Figure 3- 15 Schematic of relay circuit.

After implementing the schematic, the relay circuit would look like next figure. See figure 3-16.

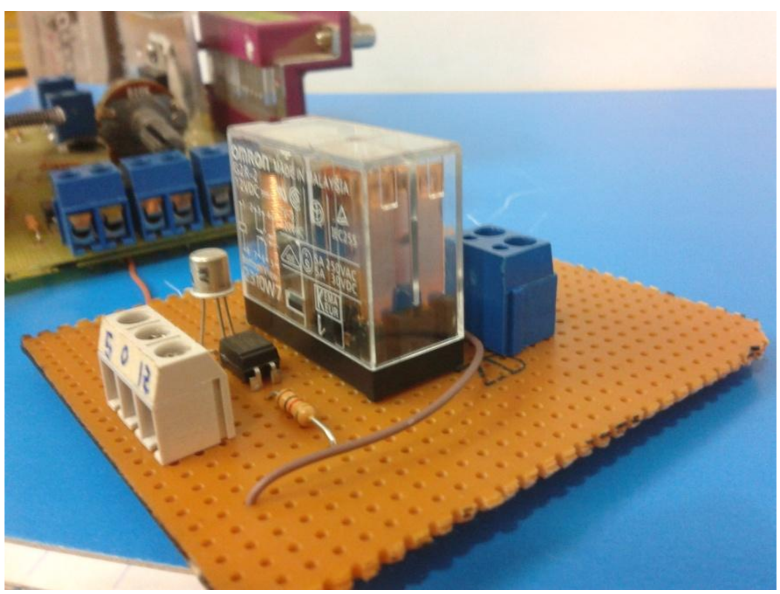


Figure 3- 16 Relay circuit.

3.5.Final Result

Finally, all the components will be placed inside plastic container to protect all the elements from mechanical shocks and from the dust. See figure 3-17.

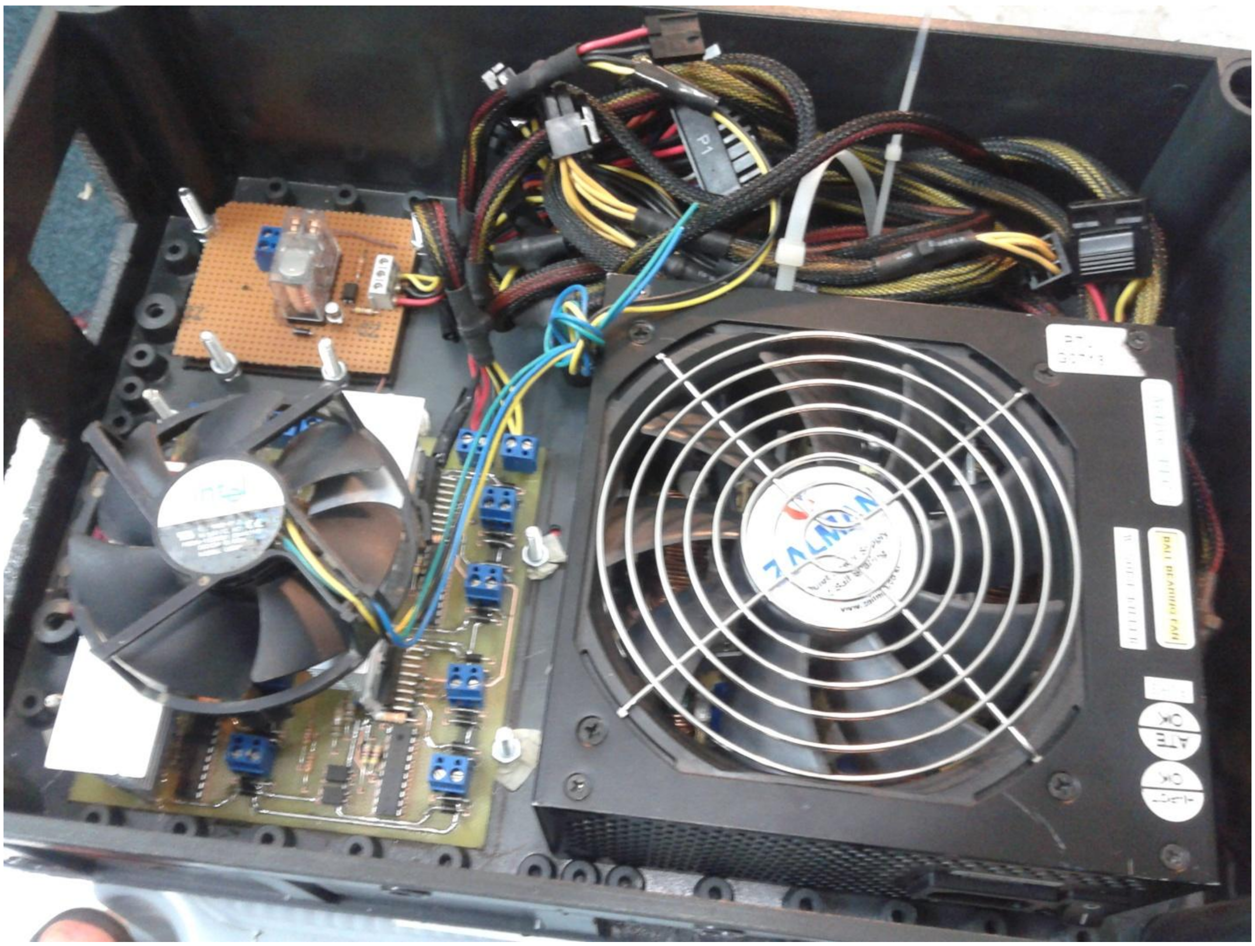


Figure 3- 17 Controller box.

4. CONFIGURING MACH3 FOR THE MACHINE

Begin with the Config>Ports and Pins dialog. Figure 4-1 shows this selection on the Config menu. The Ports and Pins dialog has many tabs, but the initial one is as shown in Figure 4-2.

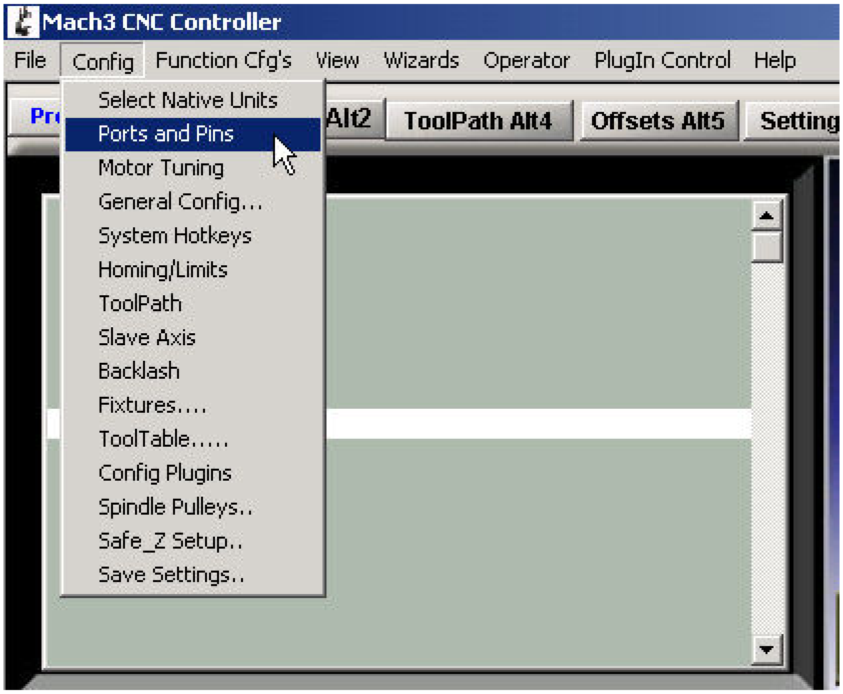


Figure 4- 1 Config dialog.

Select the Port Setup and Axis Selection tab on the Ports and Pins dialog, as shown in Figure 4-2.

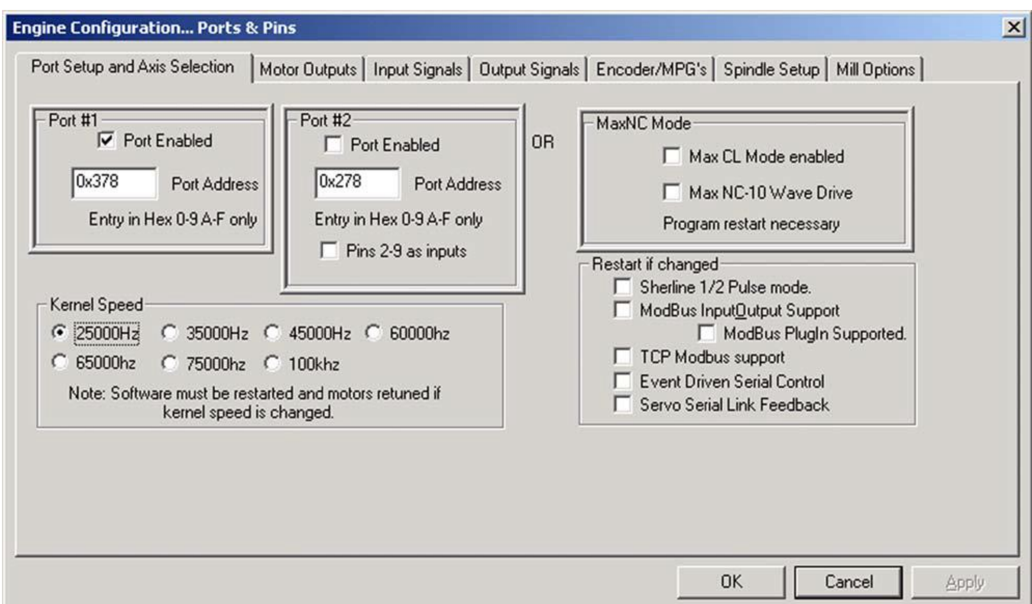


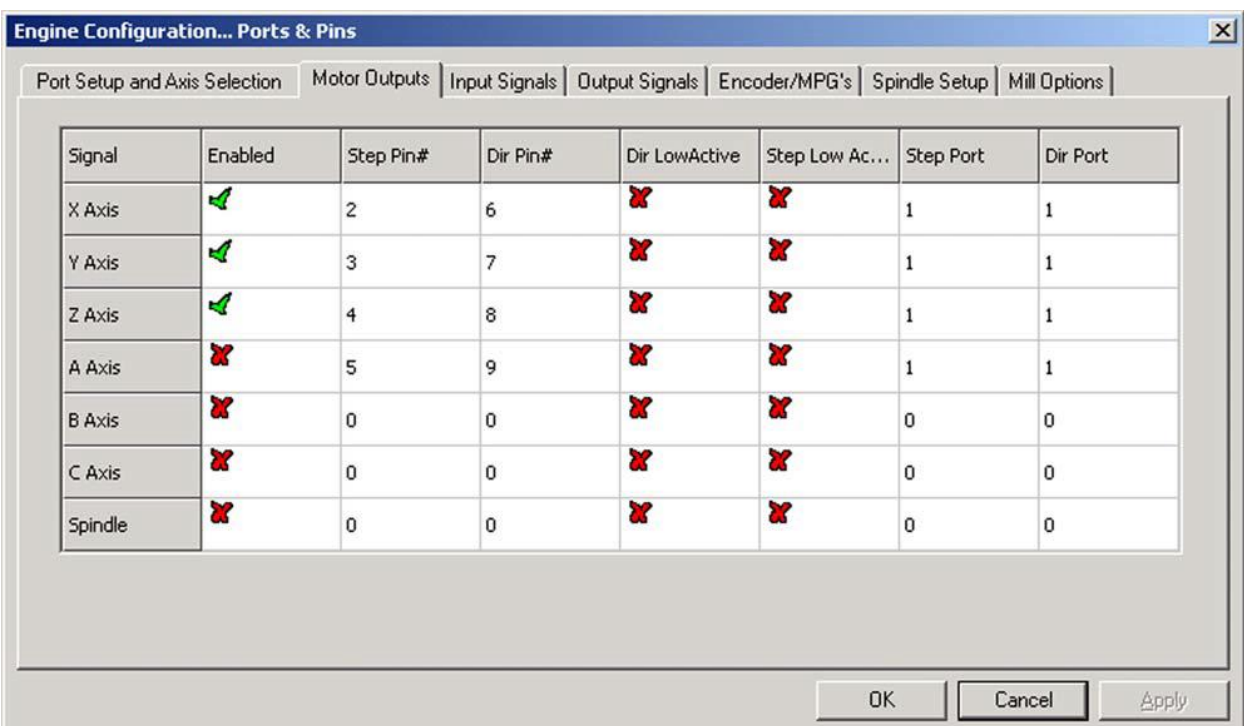
Figure 4- 2 Ports and Pins dialog.

4.1.Choosing Kernel Speed

The Mach3 driver can run at frequencies from 25,000 Hz (pulses per second) up to 100,000 Hz, depending on the speed of your processor and other loads placed on it when running Mach3. The frequency you need depends on the maximum pulse rate you need to drive any axis at its top speed. 25,000 Hz will probably be suitable for stepper motor systems. With a 10 micro-step driver such as a Gecko 201, you will get around 750 RPM from a standard 1.8 degree stepper motor with a 25,000 Hz pulse rate. Higher pulse rates are needed to achieve desired motor RPM for servo drives that have high resolution shaft encoders on the motor. Determining Axis Drive Requirements. Computers with a 1 GHz clock speed will almost certainly be able to run at 35,000 Hz, so you can choose this if you need a high step rate (for example, if you have very fine pitch lead screws). The demonstration version of Mach3 will run at 25,000 Hz only. In addition, if Mach3 is forcibly closed, then on re-start it will automatically revert to 25,000 Hz operation. The actual frequency of the running system is displayed on the standard Diagnostics screen. Click the box next to the desired kernel speed.

4.2.Axis and Spindle Output Signals to be Used

View the Motor Outputs tab of the Ports and Pins dialog. This will look similar to Figure 4-3.



Signal	Enabled	Step Pin#	Dir Pin#	Dir LowActive	Step Low Ac...	Step Port	Dir Port
X Axis	✓	2	6	✗	✗	1	1
Y Axis	✓	3	7	✗	✗	1	1
Z Axis	✓	4	8	✗	✗	1	1
A Axis	✗	5	9	✗	✗	1	1
B Axis	✗	0	0	✗	✗	0	0
C Axis	✗	0	0	✗	✗	0	0
Spindle	✗	0	0	✗	✗	0	0

Figure 4- 3 Motor outputs dialog.

Define where the drives for your X, Y and Z axes are connected, and click in the Enabled column to get a check-mark to Enable these axes. If any axis is enabled that shouldn't be, click in the Enabled column to change the green check to a red X. If you need to edit any boxes in the Step Pin #, Dir Pin #, Step Port, or Dir Port columns, double-click the appropriate boxes and edit the entries. If your interface hardware (e.g. Gecko 201 stepper driver) requires an active-lo signal, ensure that these columns are checked for the Step and Dir(ection) signals. If you have rotary or slaved axes, then you should enable and configure them. If your spindle speed will be controlled by hand, then you have finished this tab. Click the Apply but-ton to save the data on this tab. Enable the spindle if your spindle speed will be controlled by Mach3. Allocate a Step pin/port for it if using pulse width modulated control with relays to control its direction, or allocate Step and Direction pins/ports if it has full control. You should also define if these signals are active-lo. When done, click the Apply button to save the data on this tab.

4.3.Input Signals to be Used

Now select the Input Signals tab. This will look like Figure 4-4.

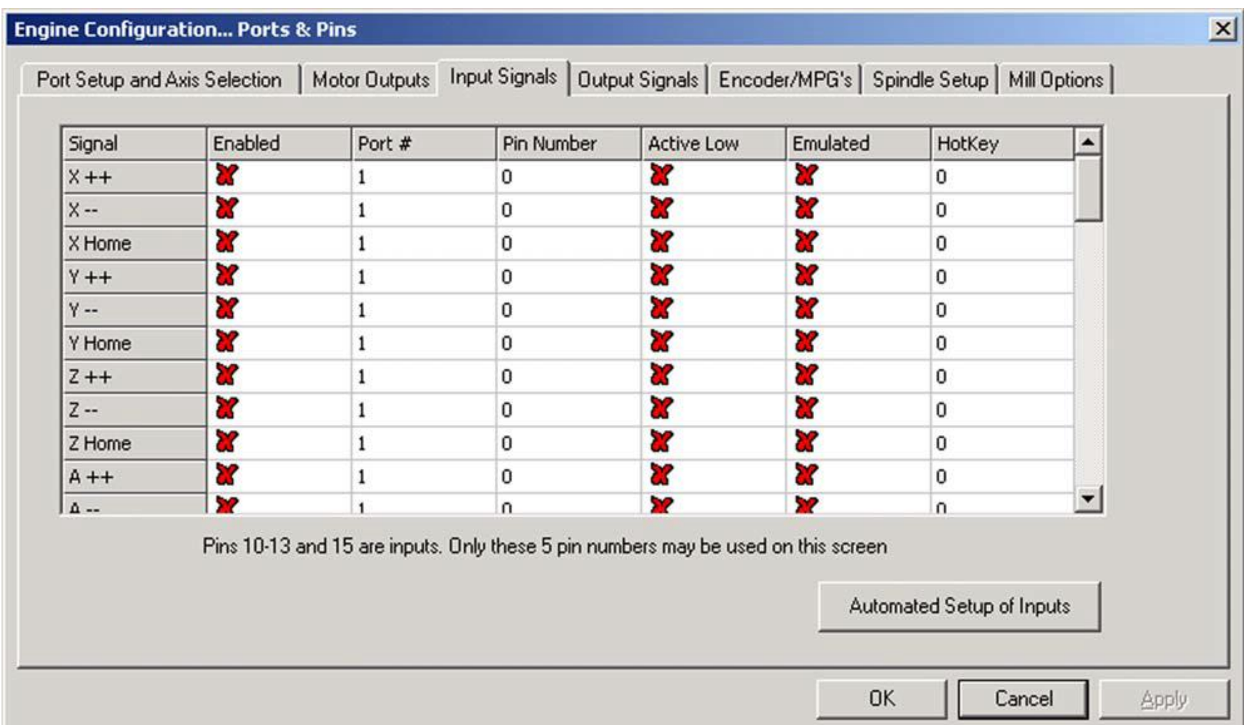


Figure 4- 4 Input signals dialog.

4.4.Steps Per Unit

Now that we know the required motor revs per unit of travel, we can finally calculate: Mach3 steps per unit = Mach3 steps per rev x Motor revs per unit Figure 4-5 shows the dialog for Config>Motor Tuning. Click a button at the right of the dialog to select the axis that you are configuring, and enter the calculated value of Mach3 steps per unit in the box labelled Steps per. This value does not have to be an integer, so you can achieve as much accuracy as you wish. Whatever the number, it is a specific, calculated number determined by the drive configuration. It is NOT a "tuneable" quantity. If you don't get the correct machine travel when testing, you have made an error in your calculation. Be sure to calculate and set a value for each axis you are using, as they may not be the same. To avoid forgetting later, click Save Axis Settings now.

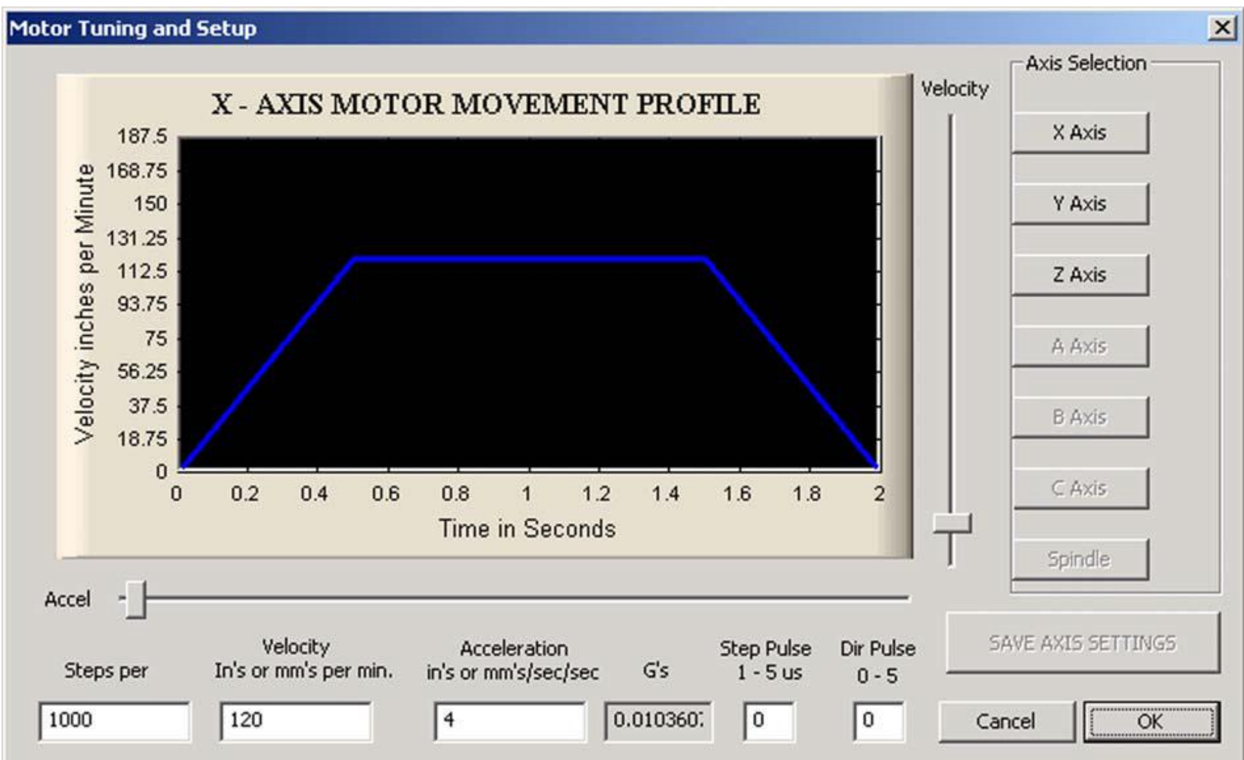


Figure 4- 5 Motor tuning and setup.