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Sudan University of Science and Technology

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Selection of the Best Design for a Numerical Control System Used for Lasers in Material Processing

اختيار أفضل تصميم لنظام تحكم رقمى يستخدم في ليزرات معالجة المواد

A thesis Submitted in Fulfillment for the Requirements of the Degree of Doctor of Philosophy

In

Laser Applications in Mechanical Engineering

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بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ
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عَلَيْهِمْ وَلَا ٱلضَّآلِّينَ ٦

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Abstract

In this research, the best design for portable CNC system to control the lasers processing materials was chosen. Many computer numerical control systems were studied and compared with each other, then the best control system parts were selected.

The tables system were chosen to control a billet with dimensions of 100 mm and 100mm in the x-axis and y-axis.

The possibility of coupling the y axis with a pneumatic system was considered in choosing the system, with minimum speed of 392 mm/s, holding torque 48.6 g.cm, a step angle of 7.5 degree and maximum speed of 3.2 mm/s. The x axis was always coupled with a stepper motor with the same specifications of the y axis.

An electronic system was selected on the basis of the Microcontroller 16f877 and the LabVIEW program was chosen so that the user can send the standard operating commands G- code which can be read by the program through the text file.

The validity of the numerical control system was verified by the execution of two tests:

The first test was done by applying Co_2 laser micro-machining of poly methyl methacrylate sheets. At which the positioning accuracy was equal to ± 0.05 mm.

In The second test, the repeatability of the system was tested. The x-axis and the y-axis were moved to a distance of 10 mm, 20 mm or 30 mm back and forth with the maximum speed and for 5 times for each distance. The axis repeatability was equal to ± 0.0025mm.

The numerical control system was selected in a way that can work with electric motor or pneumatic system.

If small step electric motor is used, the control system accuracy will be increase.

المستخلص

في هذا البحث تم اختيار افضل نظام رقمي محمول للتحكم فى ليزرات معالجة المواد. فى البدايه تم دراسة العديد من نظم التحكم الرقمى بالحاسوب ومقارنتها مع بعضهاالبعض, ومن ثم تم اختيار أجزاء نظام التحكم الأفضل.

اختيرت طاولات النظام للتحكم فى حركة مشغولة ذات ابعاد 100ملم x 100ملم فى محورين محور x ومحور y. روعي فى اختيار النظام امكانية قرن المحور y بنظام هوائى ذو سرعة دنيا 392 ملم \ ثانية أو بمحرك خطوة ذو عزم ايقاف 48.6 جرام سم وخطوة 7.5^{o} وسرعة قصوى 3.2 ملم \ ثانية والمحور x مقرون على الدوام بمحرك خطوة له نفس مواصفات المحور y.

تم اختيار منظومة الكترونية على اساس المتحكم الدقيق 16f877 و اختيار برنامج البيئة البرمجية ليمكن المستخدم من ارسال أوامر التشغيل القياسية (شفرة – ج) و التى يقرأها البرنامج من خلال الملف النصى.

بعد ذلك تم التحقق من صلاحية نظام التحكم الرقمى للتطبيق وذلك بواسطة اختبارين.

الاختبار الأول تم بتنفيذ تشغيل ميكروى بواسطة الليزرCO_2 لألواح من البولى مثيل ميثاكريلات. حيث وجد أن دقة التموضع تساوى ±0.05 ملم.

الاختبار الثانى تم فيه اختبار التكرارية للنظام حيث تم تحريك المحور x و المحور y لمسافة 10 ملم, 20ملم و 30ملم ذهاباً ورجوعاً بالسرعة القصوى وذلك لعدد 5 مرات لكل مسافة ووجد أن التكرارية للمحاور تساوى 0.0025 ± ملم.

تم اختيار نظام التحكم الرقمى بحيث يمكنه العمل بمحركات كهربائية أو منظومه هوائية.

اذا تم استخدام محركات كهربائية بخطوه أصغر فان دقة نظام التحكم ستكون أفضل.

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CHAPTER ONE

Introduction and Basic Concepts of Material Processing

1.1 Introduction:

With the on-going development of technology and economy, new industrial requirements such as high precision, good quality, high production rates and low production costs are increasingly demanded. Most of such requirements, including dimensional accuracy, conformance to tolerances of finished products and production rate can be met with better machine tools. With the help of **C**omputer **N**umerical **C**ontrol (CNC) technology, machine tools today are not limited to human capabilities and are able to make ultra-precision products down to Nano scales when laser is used as the tool (Wei Qin, 2013).

1.2 Problem Statement:

Control laser micromachining in high and low speed is the researcher's problem in institute of laser in Sudan University of Science and Technology to process different materials. So a numerical system, which can accept two types of power drive, pneumatic and electric, will be the solution.

1.3 Research objectives:

The objective of this research is to select a best design for a portable control system, X-Y table, to control laser beam so as to control material processing parameters (cutting speed, feed rate, and depth of cut) and geometry using standards G-code. The x-y table characteristic required to be precise, compact, easy to operate and capable to be manufactured using conventional technology.

1.4 Thesis structure:

The thesis consisting four chapters. Chapter one covers the material processing, types, traditional machining and nontraditional machining.

Chapter two covers the basics of the computer numerical control technology and machine parts, laser technology, used in material processing, advantages and disadvantages. At the end of chapter two the resent researches are reviewed.

Chapter three review and discuss number of control systems and at the end of the chapter a best control system is mentioned.

Chapter four illustrates the performance of the selected control system, CNC system, and it's testing and validation in addition to the conclusions and recommendations.

1.5 Materials Processing:

The series of operations that transforms industrial materials from a raw-material state into finished parts or products is called Materials processing (Ahmet Aran, 2007). The five basic families of shape production processes are:

(1) Material removal processes— Geometry is generated by changing the mass of the incoming material in a controlled and well-defined manner, e.g., milling, turning, electro discharge machining, and polishing.
(2) Deformation processes— the shape of a solid workpiece is altered by plastic deformation without changing its mass or composition, e.g., rolling, forging, and stamping.
(3) Primary shaping processes— a well-defined geometry is established by bulk forming material that initially had no shape, e.g., casting, injection molding, die casting, and consolidation of powders.
(4) Structure-change processes— the microstructure, properties, or appearance of the workpiece are altered without changing the original shape of the workpiece, e.g., Heat treatment and surface hardening.
(5) Joining and assembly processes— Smaller objects are put together to achieve a desired geometry, structure, and/or property. There are two

general types: (i) Consolidation processes which use mechanical, chemical, or thermal energy to bond the objects (e.g., welding and diffusion bonding). (ii) Strictly mechanical joining (e.g., riveting, shrink fitting, and conventional assembly) (Lee J, 1999).

1.5.1 Material Removal Processes

Processes, also known as machining, remove material by mechanical, electrical, laser, or chemical means to generate the desired shape and/or surface characteristic (Lee J, 1999).

1.5.1.1 Traditional Machining

Traditional machining processes remove material from workpiece through plastic deformation. The process requires direct mechanical contact between the tool and workpiece and uses relative motion between the tool and the workpiece to develop the shear forces necessary to form machining chips. The tool must be harder than the workpiece to avoid excessive tool wear.

In all traditional machining processes, the surface is created by providing suitable relative motion between the cutting tool and the workpiece. There are two basic components of relative motion: primary motion and feed motion. Primary motion is the main motion provided by a machine tool to cause relative motion between the tool and workpiece. The feed motion, or the secondary motion, is a motion that, when added to the primary motion, leads to a repeated or continuous chip removal. It usually absorbs a small proportion of the total power required to perform a machining operation. The two motion components often take place simultaneously in orthogonal directions (Lee J, 1999).

(a) Drilling and Reaming:

Drilling is the most widely used process for making circular holes of moderate accuracy. It is often a preliminary step to other processes such as tapping, boring, or reaming. Reaming is used to improve the accuracy of a hole while increasing its diameter. Holes to be reamed are drilled undersize. Drills are classified by the material from which they are made, method of manufacture, length, shape, number and type of helix or flute, shank, point characteristics, and size series. Table (1.1) illustrate the common drill types. Selection of drill depends on several factors:

- Hardness and composition of the workpiece, with hardness being more important.
- Rigidity of the tooling.
- Hole dimensions.
- Type of drilling machine
- Drill application — originating or enlarging holes
- Tolerances.
- Costs.

Table 1.1 Common Drill Types

Drill Type	Description	Application
Core	Has large clearance for chips	Roughing cuts; enlarging holes
General-purpose (jobber)	Conventional two-flute design; right-hand (standard) or left-hand helix. Available with flute modification to break up long chips	General-purpose use, wide range of sizes
Gun	Drill body has a tube for cutting fluid; drill has two utting edges on one side and counte r-balancing wear pads on the other side	Drill high-production quantities of holes without a subsequent finishing operation
High helix	Wide flutes and narrow lands to provide a large bearing surface	Soft materials, deep holes, high feed rates
Low helix	Soft materials, deep holes, high feed rates	Soft materials, shall ow holes
Oil hole	Has holes through the drill body for pressurized fluid	Hard materials, deep holes, high feed rate

Screw-machine	Short length, short flutes, extremely rigid	Hardmaterials; nonflat surfaces
Step	Two or more drill diameters along the drill axis	Produce multiple-diameter oles, such as for drilling/countersinking
Straight flute	Flutes parallel to the drill axis minimize torquing of the Workpiece	Soft materials; thin sheets

The most widely used drill is the general-purpose twist drill, which has many variations. The flutes on a twist drill are helical and are not designed for cutting but for removing chips from the hole.

Machining forces during reaming operations are less than those of drilling, and hence reamers require less toughness than drills and often are more fragile. The reaming operation requires maximum rigidity in the machine, reamer, and workpiece. Table (1.2) illustrates the types of common reamer.

Most reamer shave two or more flutes, either parallel to the tool axis or in a helix, which provide teeth for cutting and grooves for chip removal. The selection of the number of flutes is critical: a reamer with too many flutes may become clogged with chips, while a reamer with too few flutes is likely to chatter.

Table 1. 2 Common Reamer Types

Reamer Type	Description	Application
Adjustable	Tool holder allows adjustment of the reamer diameter to compensate for tool wear, etc.	High-rate production
End-cutting	Cutting edges are at right angles to the tool axis	Finish blind holes, correct deviations in through-holes
Floating blade	Replaceable and adjustable cutting edges to maintain tight Tolerances	High-speed production (workpiece

		rotated, tool stationary)
Gun	Hollow shank with a cutting edge (e.g., carbide) fastened to the end and cutting fluid fed through the stem	High-speed production (workpiece rotated, tool stationary)
Shell	Two-piece assemblies, mounted on arbors, can be adjusted to compensate for wear	Used for finishing operations (workpiece rotated, tool stationary)
Spiral flute	Flutes in a helix pattern, otherwise same as straight-flute reamer	Difficult to ream materials, and holes with irregularities
Straight flute	Flutes parallel to the tool axis, typically pointed with a 45° Chamfer	General-purpose, solid reamer

The optimal speed and feed for drilling depend on workpiece material, tool material, depth of hole, design of drill, rigidity of setup, tolerance, and cutting fluid. For reaming operations, hardness of the workpiece has the greatest effect on machinability. Other significant factors include hole diameter, hole configuration (e.g., hole having keyways or other irregularities), hole length, amount of stack removed, type of fixture, accuracy and finish requirements, size of production run, and cost. Most reamers are more easily damaged than drills; therefore, the practice is to ream a hole at no more than two thirds of the speed at which it was drilled (Lee J, 1999).

(b) Turning and Boring

Turning produces external cylindrical surfaces by removing material from a rotating workpiece, usually with a single-point cutting tool in a lathe. Boring is this same process applied for enlarging or finishing internal surfaces of revolution.

The basic equipment for turning is an engine lathe that consists of a bed, a headstock, a carriage slide, a cross slide, a tool holder mounted on the cross slide, and a source of power for rotating the workpiece Engine lathes are often modified to perform additional types of machining operations through the use of attachments. Most turning machines can also perform boring operations, but boring machines may not be able to perform turning operations. Sizes of lathes range from fractional horsepower to greater than 200hp. Table (1.3) illustrate lathes used for turning.

Table 1.3 Typical Lathes Used for Turning

Lathe	**Description**	**Applications**
Bench lathe	An engine lathe that can be placed on a workbench	Small workpieces and prototype parts
Engine lathe	Has a leadscrew that moves the slide uniformly along the bed; available with chucking or centering headstock	Chucking type allows centering and clamping for rotation, e.g., holding castings or forgings Centering type secures workpiece between pointed centers, e.g., for turning long workpieces, such as shafts
Gap-frame lathe	Modified engine lathe for turning larger diameter parts	Workpieces requiring off-center mounting or irregular protuberances
Numerically controlled Lathe	Uses a computer program to control the lathe to generate the desired shape	Produces consistent parts in a CAD/CAM environment

Tracer-controlled lathe	A duplicating lathe that uses a stylus moving over a template to control the cutting tool	Manufacture of prototype parts and low-rate production

Table 1. 4 Typical Machines Used for Boring

Boring Machine	**Description**	**Applications**
Bar (screw) machine	Modified turret lathe to handle bars and tubes	Parts made from bars or tubes
Engine lathe	Versatile machine; essentially same machine as used for turning	Bores one hole at a time in a single part; limitations regarding workpiece size and configuration
Horizontal boring mill	Workpiece remains stationary and tool rotates	Wide variety of parts; cost-effective for a relatively high production volume
Precision boring machine	Vertical and horizontal models	Parts requiring extreme tolerances
Special-purpose machines	Boring machine modified for specialized application	Single-purpose applications with high production rates
Turret lathe	Has rotating turret on a lathe, tooled for multiple machining operations	More versatile than engine lathe; supports high production rates
Vertical boring mill	Same basic components as a lathe	Very large, heavy, or eccentric workpieces
Vertical turret lathe	Same features as vertical boring mill; may also have a econd	Flexible machine, useful in

	vertical head	CAD/CAM environment; simultaneous multiple machining operations possible

Machines used for boring are noted for their rigidity, adaptability, and ability to maintain a high degree of accuracy. For extremely large workpieces, weighing thousands of pounds, the boring cutting tool is rotated and the workpiece is fixed.

In turning and boring operations, a single-point tool is tra-versed longitudinally along the axisymmetric workpiece axis parallel to the spindle. A tangential force is generated when the cutting tool engages the rotating work. This force is generally independent of the cutting speed and directly proportional to the depth of cut for a particular material, tool shape (particularly side rake angle), and feed rate. That force, when multiplied by the surface speed of the workpiece, estimates the net horsepower required to remove material (Lee J, 1999).

(c) Planning and Shaping:

Planning is a widely used process for producing flat, straight surfaces on large workpieces. A variety of contour operations and slots can be generated by use of special attachments. It is often possible to machine a few parts quicker by planning than by any other method. Shaping is a process for machining flat and contour surfaces, including grooves and slots. Planers develop cutting action from straight-line reciprocating motion between one or more single-point tools and the workpiece; the work is reciprocated longitudinally while the tools are fed sideways into the work. Planer tables are reciprocated by either mechanical or hydraulic drives, with mechanical drives predominating. Table (1.5) illustrate the types of planners.

Shapers use a single-point tool that is supported by a ram which reciprocates the tool in a linear motion against the workpiece. The workpiece rests on a flat bed and the cutting tool is driven toward it in small increments by ram strokes. Shapers are available with mechanical and hydraulic drives, with mechanical drives predominating.

Planning and shaping are rugged machining operations during which the workpiece is subjected to significant cutting forces. These operations require high clamping forces to secure the workpiece to the machine bed (Lee J, 1999).

Table 1.5 Types of Planers

Planer Type	Description	Applications
Double housing	Two vertical uprights support the cross rail which in turn supports the tools	Rigid machine; restricts the width of workpiece
Open side	A single upright column supports a cantilevered cross rail; less rigid than the double-housing type	Accommodates wide workpieces which can overhang one side of the table without interfering with the planer operation

shaper Type	Description	Applications
Horizontal	The ram drives the tool in the horizontal direction; uses plane or universal table (rotates on three axes)	Gears, splined shafts, racks, and so on; not used for rate production
Vertical	The ram operates vertically, cutting on the down stroke	Slots, grooves, keyways; matching die sets, molds, fixtures; not used for rate production

(d) Milling:

Milling is a versatile, efficient process for metal removal. It is used to generate planar and contour surfaces through the action of rotating multiple-tooth cutters. Surfaces having almost any orientation can be machined because both the workpiece and cutter can move in more than one direction at the same time. Cutters with multiple cutting edges rotate in a spindle. The machining process is interrupted as the teeth of the milling cutter alternately engage and disengage from the workpiece. Most milling is done in machines designed for milling can also be done by any machine tool that can rigidly hold and rotate a cutter while feeding a workpiece into the cutter Milling machines are usually classified in terms of their appearance: knee-and-column, bed-type, planar-type, and special purpose. The knee-and-column configuration is the simplest milling machine design. The workpiece is fixed to a bed on the knee and the tool spindle is mounted on a column. For very large workpieces, gantry or bridge-type milling machines are used. Machines having two columns can provide greater stability to the cutting spindle(s). Special-purpose machines are modifications of the three basic models. The usual power range for knee-and-column machines is 1 to 50 hp (0.75 to 37 kW). Bed-type machines are available in a wide range of sizes, up to 300 hp (225 kW). Planar-type machines are

Available from 30 to 100 hp (22 to 75 kW). Table (1.6) illustrate types of milling machines (Lee J, 1999).

Table 1.6 Types of Milling Machines

Milling machine	Description	Applications
Knee-and-column	Six basic components: • Base — the primary support • Column — houses spindle and drive	Widely used for low production milling; provides three-axis movement;

	• Overarm — provides support for the arbor-mounted cutting tools • Knee-supports the table, saddle, and workpiece; provides vertical movements. • Saddle-provides 1°of horizontal motion. • Table- directly supports the workpiece and provides a second degree of horizontal motion.	primary drawback is lack of rigidity due to the number of joints
Bed-type	Table and saddle mounted on a bed in fixed vertical position; vertical motion obtained by movement of the spindle carrier; available with horizontal or vertical pindle	Very rigid machine; permits deep machining cuts and close dimensional control
Planar-type (adjustable rail)	Can accommodate almost any type of spindle for driving cutters and boring bars; utilizes several milling heads	Use for mass-production milling; can perform simultaneous milling and boring operations
Special purpose	Many possible configurations involving major modifications or combinations of the basic types of milling machines; adapted for automated control	Optimized for high-volume production; includes rofilers and machining centers; these machines are capable of performing multiple simultaneous machining operations

(e) Broaching:

Broaching is a precision machining process. It is very efficient since both roughing cuts and finishing cuts are made during a single pass of the broach tool to produce a

Smooth surface, and further finishing is usually not necessary. Consequently, close tolerances can be readily achieved at a reasonable cost for high rates of production.

Broaches are expensive multitoothed cutting tools. Thus, the process is usually employed for low or high production when broaching is the only practical method to produce the required dimensional tolerance and surface quality. An example of the latter case is the dovetail slots in jet engine turbine disks.

Broaching is a machining process similar to planing. A broach is essentially tapered bar into which teeth are cut, with the finishing teeth engaging last on the end with the larger diameter. A single broach has teeth for rough cutting, semi finishing, and finishing. Broaching involves pushing or pulling a broach in a single pass through a hole or across a surface. As the broach moves along the workpiece, cutting is gradual as each successive tooth engages the workpiece, removing small amount of material. Overall machining forces are much greater than that of other machining methods, and consequently broaching is considered to be the most severe of all machining operations. Table (1.7) illustrate types of broaches.

Broaching machines are categorized as horizontal or vertical, depending on the direction of broach travel. Industry usage is almost evenly divided between these two categories. The selection of machine type depends heavily on the configuration of the workpiece and available space in the factory, considering both floor space and

Vertical clearance requirements (Lee J, 1999).

Table 1.7 Types of Broaches

Broaches	Description	Applications
Solid	One-piece broach produced from tapered bar stock; repair of broken teeth is difficult	Parts which require high dimensional accuracy and concentricity
Shell	Multipiece broach consisting of a main body, an arbor section over which a removable shell fits, and a removable shell containing the cutting edges; worn or damaged sections can be replaced	Internal and selected external broaching; sacrifices some accuracy and concentricity as the tool is not as stiff as a solid roach
Insert-type	Effectively a tool holder with inserts to perform the actual cutting; inserts are typically made from HSS or carbides; worn or damaged inserts can be readily replaced	Broaching large, flat urfaces

(f) Grinding:

Grinding, or abrasive machining, refers to processes for removing mate-rial in the form of small chips by the mechanical action of irregularly shaped abrasive grains that are held in place by a bonding material on a moving wheel or abrasive belt. In surface-finishing operations (e.g., lapping and honing) these grains are suspended in a slurry and then are embedded in a roll-on or reference surface to form the cutting tool. Although the methods of abrasion may vary, grinding and surface-finishing processes are used in manufacturing when the accuracy of workpiece dimensions and surface requirements are stringent and the material is too hard for conventional machining.Grinding is also used in cutoff work and cleaning of rough surfaces, and some methods offer high material-removal rates suitable for shaping, an area in which milling traditionally has been used. Grinding is applied mainly in metalworking because abrasive grains are harder than any metal and can shape the toughest of alloys. In addition, grinding wheels are available for machining plastics, glass, ceramics, and stone. Conventional precision metal and ceramic components and ultraprecision electronic and optical components are produced using grinding.

Three types of energy are involved in grinding. Rubbing energy is expended when the grains (cutting edges) of the grinding wheel wear down. As they wear, they cut less and produce increasing friction, which consumes power but removes less material. Plowing energy is used when the abrasive does not remove all of the material but rather plows some of it aside plastically, leaving a groove behind. Chip-formation energy is consumed in removing material from the workpiece as the sharp abrasive grain cuts away the material (or chip) and pushes it ahead until the chip leaves the wheel. Table (1.8) illustrates the common grinding wheel abrasives (Lee J, 1999).

Table 1.8 Common Grinding Wheel Abrasives

Abrasive	Characteristic	Grinding Application
Aluminum oxide	Friable	Steel: soft or hardened, plain or alloyed
Seeded gel aluminum Oxide	More friable and expensive than aluminum oxide	Steel: soft or hardened, plain or alloyed; use at higher stock rem oval rates
CBN	Tough; increased life at higher speeds; high accuracy and finish	Hardened steels; tough superalloys
Synthetic diamond	Hardest of all abrasives; can be friable; seldom need dressing/truing	Grinding hardened tool steels, cemented carbides, ceramics, and

		glass; cutting and slicing of silicon and germanium wafers
Silicon carbide	Friable	Cast iron; nonferrous metals; nonmetallics

1.5.1.2 Nontraditional Machining:

Many new materials are either harder than conventional cutting tools or cannot withstand the high cutting forces involved in traditional machining. Nontraditional manufacturing (NTM) processes can produce precision components of these hard and high-strength materials. NTM processes remove material through thermal, chemical, electrochemical, optical, and mechanical (with high impact velocity) inter-actions (Mikell P. Groover, 2010).

(a) Electrical Discharge Machining (EDM):

The EDM process machines hard materials into complicated shapes with accurate dimensions. EDM requires an electrically conductive workpiece. Process performance is unaffected by the hardness, toughness, and strength of the material. However, process performance is function of the melting temperature and thermal conductivity. EDM is currently widely used in aerospace, machinery, and die and mold industries.

There are two types of EDM processes:

- Die-sinking EDM uses a pre-shaped tool electrode to generate an inverted image of the tool on the workpiece; commonly used to generate complex-shaped cavities and to drill holes in different geometric shapes and sizes on hard and high-strength materials.
- Wire EDM (WEDM) uses a metal wire as the tool electrode; it can generate two- or three-dimensional shapes on the workpiece for making punch dies and other mechanical parts.

EDM removes workpiece materials by harnessing thermal energy produced by pulsed spark discharges across a gap between tool and workpiece. A spark discharge generates a very small plasma channel having a high energy density and a very high temperature (up to 10,000°C) that melts and evaporates a small amount of workpiece material. The spark discharges always occur at the highest electrical potential point that moves randomly over the machining gap during machining. With continuous discrete spark discharges, the workpiece material is uniformly removed around the tool electrode. The gap size in EDM is in the range of 400 μ in. to 0.02 in. (0.01 to 0.5 mm), and is determined by the pulse peak voltage, the peak discharge current, and the type of dielectric fluid.

The discharge energy during EDM is provided by a direct current pulse power generator. The EDM power system can be classified into RC, LC, RLC, and transistorized types. The transistorized EDM power systems provide square waveform pulses with the pulse on-time usually ranging from 1 to 2000 m sec, peak voltage ranging from 40 to 400V, and peak discharge current ranging from 0.5 to 500 A. With the RC, LC, or RLC type power system, the discharge energy comes from a capacitor that is connected in parallel with the machining gap. As a result of the low impedance of plasma channel, the discharge duration is very short (less than 5 m sec), and the discharge current is very high, up to 1000 A. The peak voltage is in the same range of transistorized power systems.

The transistorized power systems are usually used in die-sinking EDM operations because of their lower tool wear. Capacitive power systems are used for small hole drilling, machining of advanced materials, and micro-EDM because of higher material removal rate and better process stability. WEDM power generator usually is a transistor-controlled capacitive power system that reduces the wire rupture risk. In this power system, the discharge frequency can be controlled by adjusting the on-time and off-time of the transistors that control the charging pulse for the capacitor connected in parallel with the machining gap (Lee J, 1999).

(b) Electrical Chemical Machining (ECM):

The ECM process uses the electrochemical anodic dissolution effect to remove workpiece material. Like die-sinking EDM, the tool electrode of ECM is pre-shaped according to the requirements of the workpiece. During machining, the inverted shape of the tool is gradually generated on the workpiece. ECM machines complex contours, irregular shapes, slots, and small, deep, and/or noncircular holes. Typical applications of ECM include machining nickel-based super alloy turbine blade dovetails, slots in super alloy turbine disks, engine castings, gun barrel rifles, and forging dies. ECM is also used for deburring, surface etching, and marking.

Electrolyte fluid is forced through the gap between tool and workpiece during ECM. A low-voltage and high-current DC power system supplies the machining energy to the gap. The tool electrode of ECM must be connected as cathode and the workpiece must be connected as anode. The electrochemical anodic dissolution phenomenon dissolves workpiece surface material into metal ions. The electrolyte fluid flushes the metal ions and removes heat energy generated by the depleting actions. The gap size in ECM is in the range of 0.004 to 0.04 in. (0.1 to 1 mm). ECM process performance is independent of the strength, hardness, and thermal behavior of workpiece and tool materials.

Copper, brass, stainless steel, and titanium are commonly used as ECM tool electrode materials due to their good electrical conductivity, resistance to chemical erosion, and ease of being machined into desired shapes. The geometric dimensions of the machined surface generated by ECM depend on the shape of tool and the gap size distribution. The structure of an EC machine varies with the specific applications. An ECM must have a tool feed system to maintain the machining gap, a power system to supply the power energy, and a fluid-circulating system to supply the electrolyte and to flush the machining gap. The power system used in ECM is a DC power source with the voltage ranging from 8 to 30 V and a high current in the range of 50 to 50,000 A, depending on the specific design of the power system. The Electrolyte is the medium enabling the reaction of electrochemical dissolution occurring on the anode. The electrolyte can be classified into categories of aqueous and nonaqueous, organic and nonor-ganic, alkaline and neutral, mixed and nonmixed, and passivating and nonpassivating, and acidic. The electrolyte is selected according to the type of workpiece material, the desired accuracy, surface finish requirements, and the machining rate. Neutral salts are used in most cases. Acid electrolytes are used only for small hole drilling when the reaction products must be dissolved in the electrolyte (Lee J, 1999).

(c) Water and Abrasive Jet Machining:

Water jet machining (WJM) and abrasive water jet machining (AWJM) are used in many applications. In the WJM process, relatively soft workpiece materials are cut by a high-velocity water jet; e.g., food, wood, paper, plastic, cloth, rubber, etc. The AWJM process uses the fine abrasive particles mixed in the water jet to machine harder workpiece materials. The AWJM is used for drilling, contour cutting, milling, and deburring operations on metal workpieces, as well as for producing cavities with controlled depths using multipass and non-through-cutting methods. The cutting path of the WJM and AWJM can be controlled by a CNC system according to a preprogrammed program.

During WJM, the workpiece material is removed by the mechanical energy generated by the impact of a high-velocity water jet. In a water jet machine, a high-pressure pumping system increases the pressure of water in the pipe system, and the pressurized water is sprayed from a nozzle with a small diameter to generate a high-velocity water jet.

In the AWJM process, pressurized water is sprayed from an orifice in the nozzle body into a mixing chamber to generate a negative pressure that absorbs the abrasive particles (supplied by an abrasive feed hose) into the water jet. The water jet/abrasive grain mixture is then sprayed through a tungsten carbide nozzle. The abrasive grains in the high-velocity water jet provide small cutting edges that remove

Material. The relative distance between water jet nozzle and workpiece is controlled by a two- or three-dimensional CNC system. This process can be used to generate a complicated shape.

The key parameters are the water and/or abrasive flow velocity, abrasive grain size, and mixing tube (nozzle) length and diameter. The typical water flow velocity is in the range of 2000 to 3000 ft/sec (600 to 900 m/sec) as determined by the water pressure. The water pressure in WJM and AWJM is very high, up to 2.7 ×106 psi (400 MPa), and the nozzle diameter is in the range of 0.003 to 0.08 in. (0.8 to 2 mm). The abrasive flow rate is governed by the water flow rate and the mixing density, and can be controlled up to 10 g/sec. Abrasive particles are usually in the range of 60 to 150 mesh size. Increasing water jet flow velocity increases cutting depth. The taper error of cutting is determined by the traverse rate that describes the ratio between the material removal and the cutting depth and width. This parameter is influenced by the water and abrasive velocity and cutting speed. Proper selection of AWJ parameters is essential for the elimination of burrs, delamination’s, and cracks.

Limitations of the process include stray cutting and surface waviness, high equipment costs, hazard from the rebounding abrasive, high noise levels, and short nozzle lifetimes due to wear and abrasion (Lee J, 1999).

(d) Ultrasonic Machining:

Ultrasonic machining (USM) is a process that uses the high velocity and alternating impact of abrasive particles on the workpiece to remove material. The abrasive particles are mixed in a slurry that fills the machining gap between the tool and workpiece. The alternating movement of abrasive particles is driven by the vibration of the frontal surface of tool at an ultrasonic frequency. The ultrasonic machining process can machine hard and brittle materials.

USM is often used for machining of cavities and drilling of holes on hard and brittle materials including hardened steels, glasses, ceramics, etc. Rotary ultrasonic machining (RUM) is a new application that uses a diamond grinding wheel as the tool for drilling, milling, and threading operations. During RUM, the tool is rotating at a high speed up to 5000 rpm and vibrating axially at ultrasonic frequency. This process is able to drill holes with diameter from 0.02 to 1.6 in. (0.5 to 40 mm) at depths up to 12 in. (300 mm). The material removal rate of 6 mm 3/sec can be obtained with the RUM process. The tolerance of ±300 μin. (±0.007 mm) can be easily achieved with both conventional and rotary ultrasonic processes.

In the USM process, the machining gap between tool and workpiece is filled With an abrasive slurry composed of an oil mixed with abrasive particles, with the frontal surface of the tool vibrating at ultrasonic frequency to provide the machining energy. The inverted shape of the tool is gradually generated on the workpiece. Material removal by the USM process is very complex. When the machining gap is small, the material may be removed as the frontal surface of the tool moves toward

The workpiece, hitting an abrasive particle that impacts the workpiece surface. Material can also be removed by the impact of the abrasive particles when the machining gap is relatively large. In this case, the abrasive particles are accelerated by the pressure of slurry due to the ultrasonic vibration of the frontal surface of the tool. Also, ultrasonic-induced alternating pressure and cavitation in the slurry assist material removal.

The ultrasonic vibration in USM is generated by an ultrasonic generator. The ultrasonic generator consists of a signal generator, a transducer, and a concentrator. The signal generator produces an electrical signal whose voltage and/or current is changing at an ultrasonic fre-quency to drive the transducer. The frequency of the electrical signal can be adjusted in the range of 10 to 40 kHz.

The transducer converts the electrical voltage or current into the mechanical vibration. Two types of transducers are commonly used in USM: magnetostrictive and piezoelectric.

In the ultrasonic machine, the ultrasonic generator is held vertically on the ram that moves vertically, and the workpiece is mounted on an x-y table that determines the relative position between tool and workpiece. During machining, a force providing pressure between the tool and workpiece is added through the ram mechanism (Lee J, 1999).

(e) Electron beam:

Uses a high velocity stream of electrons focused on the workpiece surface to remove material by melting and vaporization. An electron beam gun generates a continuous stream of electrons that is accelerated to approximately 75% of the speed of light and focused through an electromagnetic lens on the work surface. The lens is capable of reducing the area of the beam to a diameter as small as 0.025mm.On impinging the surface, the kinetic energy of extremely high density that melts or vaporizes the material in a much localized area.

Electron beam machining is used for variety of high-precision cutting application in any known material. Application include drilling of extremely small diameter holes-down to 0.025 mm diameter. Drilling of holes with very high depth-to-diameter ratio-more than 100:1 and cutting of slots that are only about 0.025 mm wide. These cuts can be made to very close tolerances with no cutting forces or tool wear. The process is ideal for micromachining and is generally limited to cutting operations in thin parts – in range 0.25 to 0.63 mm thick. EBM must be carried out in a vacuum chamber ton eliminate collision of the electrons with gas molecules (Mikell P. Groover, 2010).

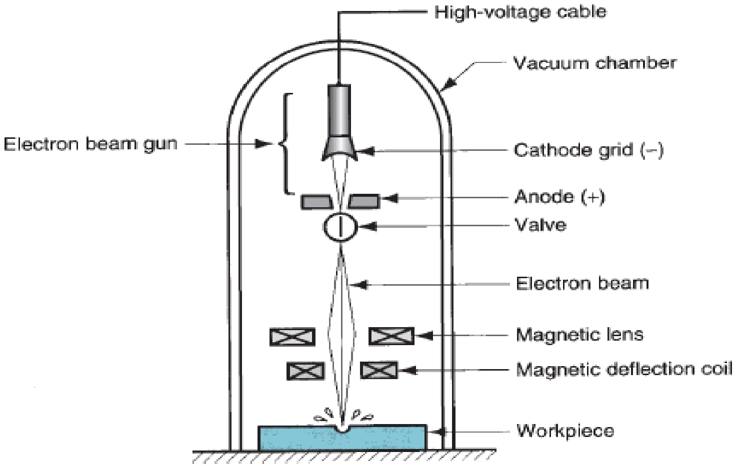


Figure 1.1 Electron beam machining

(f) Laser beam machining (LBM):

Lasers are being used for a variety of industrial applications, including heat treatment, welding, measurement, as well as scribing, cutting, and drilling. The term laser stand for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. A laser is an optical transducer that converts electrical energy into a highly coherent light beam. A laser light beam has several properties that distinguish it from other forms of light. It is monochromatic and highly collimated.

Laser beam machining (LBM) uses the light energy from a laser to remove material by vaporization and ablation. The types of laser used in LBM are carbon dioxide gas lasers and solid-state lasers. In laser beam machining, the energy of the coherent light beam is concentrated not only optically but also in terms of time.

LBM is used to perform various types of drilling, slitting, slotting, scribing, and marking operations. Drilling small diameter holes is possible – down to 0.025 mm. The range of work materials that can be machined by LBM is virtually unlimited. Ideal properties of a material for LBM include high light energy absorption, poor reflectivity, good thermal conductivity, low specific heat, low heat of fusion, and low heat of vaporization (Mikell P. Groover, 2010).

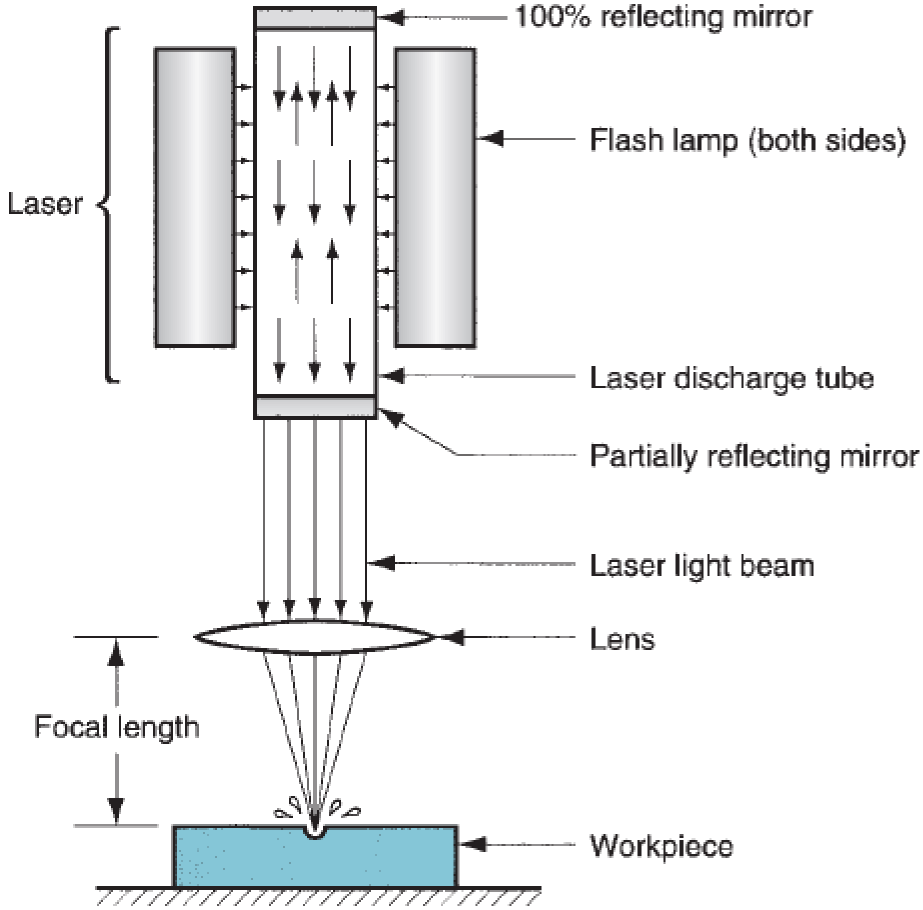


Figure 1. 2 Laser beam machining

CHAPTER TWO

Lasers in CNC technology

2.1 Introduction:

Numerical control (NC) is the operation of a machine tool by a series of coded instructions consisting of numbers, letters of the alphabet, and symbols that the machine control unit (MCU) can understand. These instructions are changed into electrical pulses of current that the machine's motors and controls follow to carry out manufacturing operations on a workpiece. The numbers, letters, and symbols are coded instructions that refer to specific distances, positions, functions, or motions, that the machine tool can understand as it machines the workpiece (Steve Krar, 2001).

2.2 History of NC:

In 1947, the U.S. Air Force found that the complex designs and shapes of aircraft parts such as helicopter rotor blades and missile components were causing problems for manufacturers, who could not keep up to projected production schedules. At that time, John Parsons, of the Parsons Corporation, of Traverse City, Michigan, began experimenting with the idea of making a machine tool generate a “thru-axis curve" by using numerical data to control the machine tool motions. In 1949, the U.S. Air Material Command awarded Parsons a contract 2 to develop NC and in turn speed up production methods. Parsons subcontracted this study to the Servomechanism Laboratory of the Massachusetts Institute of Technology (MIT), which in 1952 successfully demonstrated a vertical spindle Cincinnati Hydrotel, which made parts through simultaneous three-axis cutting tool movements. In a very short period of time, almost all machine tool manufacturers were producing machines with NC.

At the 1960 Machine Tool Show in Chicago, over a hundred NC machines were displayed. Most of these machines had relatively simple point-to-point positioning, but the principle of NC was now firmly established. From this point, NC improved rapidly as the electronics industry developed new products. At first, miniature electronic tubes were developed, but the controls were big, bulky, and not very reliable. Then solid-state circuitry and, eventually, modular, or integrated circuits were developed. The control unit became smaller, more reliable, and less expensive. The development of even better machine tools and control units helped spread the use of NC from the machine tool industry to all facets of manufacturing (Steve Krar, 2001).

2.3 NC Evolve into CNC:

The introduction of software-based controls in the early 1970s replaced the NC hardware design with complete computer logic that had more capacity and could be programmed for a variety of functions at any time. This made it possible to revise, modify, or update CNC programs or parts of programs at any time on a computer. In turn, CNC machines became easier to use with their menu-selected displays, advanced graphics, and ease of programming (Steve Krar, 2001).

2.4 CNC Applications:

The applications of CNC include both for machine tool as well as non-machine tool area. In the machine tool category, CNC is widely used for lathe, drill press, milling machine, grinding unit, laser, sheet-metal press working machine, tube bending machine etc. Highly automated machine tools such as turning center and machining center which change the cutting tools automatically under CNC control have been developed. In the non-machine tool category, CNC applications include welding machines, coordinate measuring machine, electronic assembly, tape laying filament winding machines for composites etc.

2.5 Advantages and Limitations:

The benefits of CNC are (1) high accuracy in manufacturing, (2) short production time, (3) greater manufacturing flexibility, (4) simpler fix-Turning, (5) contour machining (2 to 5-axis machining), (6) reduce human error. The drawbacks include high cost, maintenance, and the requirement of skilled part programmer.

2.6 Elements of CNC:

A CNC system consists of three basic components:

1. Machine tool (lathe, drill press, milling machine etc.).
2. Part program.
3. Machine control unit (MCU) (Er. M. S. Sehrawat, 2005)

2.6.1 Machine tool:

This can be any type of machine tool or equipment. In order to obtain high accuracy and repeatability, the design and make of the machine slide and the driving leadscrew of a CNC machine is of vital importance. The slides are usually machined to high accuracy and coated with anti-friction material such as PTFE (Poly Tetra Floro Ethyline) and Turcite in order to reduce the stick and slip phenomenon. Large diameter recirculating ball screws are employed to eliminate the backlash and lost motion. Other design features such as rigid and heavy machine structure; short machine table overhang, quick change tooling system, etc. also contribute to the high accuracy and high repeatability of CNC machines.

2.6.1.1 Main structure of CNC machine tool:

The main structure of CNC machine tool comprises of a bed, a column or any other member, such as head stock of lathe, which is rigidly connected to the bed.

The basic structure of machine tool transmits cutting force from work-piece to the foundation. There are two types of forces which act upon:

- Static forces.
- Inertia forces.

The static forces are exerted commonly by the weight of machine tool itself and pressure of the cutting tool on the workpiece. However, inertia forces are exerted by rapid acceleration and de-acceleration. Both of the forces tend to bending or deforming the table and this may lead to errors to the tune of $40\mu mm$.The bending and deformation can also be caused due to the heat effect in the machine. The heat effect can put tool holder out of alignment and deform the machine bed and table. Another cause for the deformation of vertical columns may be the mounting of driving motors directly on the cutting arm (Er. M. S. Sehrawat, 2005).

2.6.1.2 Slide and Slide-ways:

The general machine tools are provided with tables, slides, carriage. to carray the workpieces or cutting tools. These parts are sliding in nature and mounted on the ways that are fixed on the other parts (column, housing, bed or knee) of the machines known as sliding ways. These slide-ways should be rigid, accurately designed and durable. The slip-stick motion which prevents smooth starting from the rest. To overcome this drawback many anti-friction bearing arrangements are done to substitute sliding friction with rolling friction. Different methods to achieve this phenomenon are as:

A. Hydrostatic type slide-ways.
B. Anti-friction type slide-ways.
C. Wear resistant slide-ways (Er. M. S. Sehrawat, 2005).

A. Hydrostatic type slide-ways:

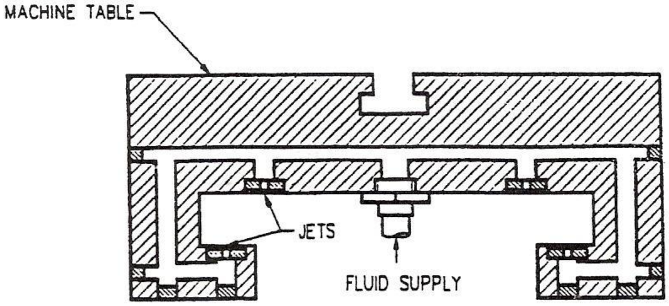
The slide-ways of many machines and particular those with a horizontal bed like lathes, exit under difficult conditions for cutting forces falling on the sliding surfaces, it will lead to increase friction and wear along with loss of accuracy. Hence, a constant film of some fluid like oil or air prevents metallic contact between the sliding members and thus reduces wear to a minimum.

Hydrostatic slide-ways can be sub-classified as:

- Oil lubricated slide-ways.

- Air bearing slide-ways.

(i) Oil lubricated slide-ways. Stress is made on maintaining an unbroken oil film. The friction is minimize by forcing oil under pressure between the mating surfaces and the pressure is automatically varied. According to the load on the surface resulting from the weight of moving member and cutting conditions. These type of slide-ways are best suitable for CNC milling machines.



SECTION THROUGH HYDROSTATIC SLIDE

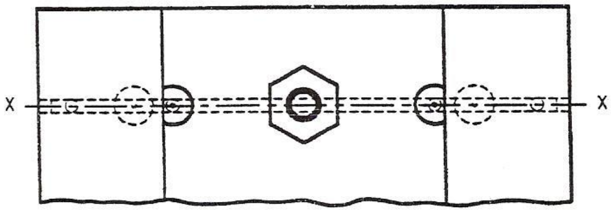


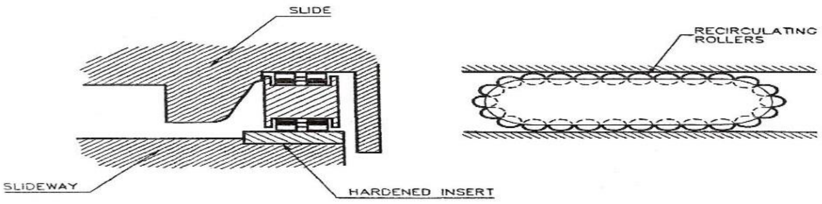
Figure 2. 1 Hydrostatically lubricated Slide-ways

(ii) Air Bearing Slide-ways. In some of the hydrostatically lubricated machines compressed air is used instead of oil. During machining compressed air is used instead of oil. During the actual displacement of the slides, the table and saddle are raised on the cushion of compressed air which entirely separates the slide and slide-ways surfaces. But air bearings are only suitable for positioning work such as drilling, because machining does not take place during the movement of slide. These bearings have a drawback that there may be mis-alignment due to lifting of slides and on the other hand, due to an unevenly situated load on the work table. The cross-section of the air bearing slide-ways are explained in the figure 2.1.

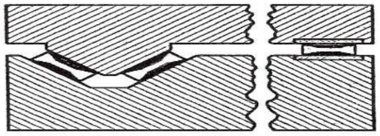
B. Anti-friction type slide-ways. Conventional slides, having sliding friction have a highest value of friction at lowest velocity. This leads to a jerky action due to sticking of oil lubricated sliding surfaces. To avoid this situation a point or line contact is made instead of surface between the sliding parts, there by converting sliding friction into rolling friction.

(i) Ball bearing guide-ways. The bed form the guide-ways for the balls, which are carried in chain cages, Hardened inserts are fitted into the table which is located on the ball track with a single flat surface in contact with the balls. The recirculating linear ball bearing uses the balls to roll between four rods, two fixed to the table and two to the stationary bed. A return groove is provided in the moving member to allow the balls to circulate, with the help of deflector plates.

(ii) Roller bearing guide-ways. To improve the load bearing properties, hardened steel inserts known as rollers are used in slide-ways to minimize friction and have a small starting effort. These usually roll between the hardened tracks of v-shaped grooves (Er. M. S. Sehrawat, 2005).



RECIRCULATING ROLLER SLIDE



VEE AND FLAT ROLLER SLIDE

Figure 2. 2 Anti-Friction Slide-ways

2.6.1.3 Wear Resistant Slide-ways:

The machine tools vary in ability to resist wear and tear of their guide-ways. Machines, such as lathe and planning machines operate under heavy loads whereas grinding machines have very less wear and tear on their slide-ways. For economic reasons, cast iron is used for the body of both types of machines. Hence a different type of bearing surfaces is applied. Method used for this purposes are:

- Flame hardening
- Induction hardening
- Fastening hardening surfaces
- Surface coatings

The first two methods are mostly applied to the conventional machines for a wear resistant slide-ways. Fastening of hardened steel strips on the slides is generally observed by scraping the saddle or bed first and then fitting a pre-measure steel strips on it. Sometimes, in the latest machines, the slide-ways are coated with a strip of low friction plastic material such as PTFE (Poly Tetra Floro Ethyline) which are employed to maintain a positive contact, another material, truncate liners are also pasted as anti-stick slip liners (Er. M. S. Sehrawat, 2005).

2.6.1.4 Spindle:

It is live part of the machine tool which gets the power from its drive unit and deliver to the work in case of lathe or to the tool in case of drilling or milling machines. In case of lathe machine, it also holds the work piece. There are three main functions of the spindle as:

- Centering the job or the tool
- Holding the job or the tool
- Rotating the job or the tool

So, on the basis of above functions, it should be stiff and short in length to get increased stability and minimization of torsional strain. It should also be very close to the front bearing as much as possible to maintain stability and smooth operation. The spindles are mounted on the anti-friction bearings. The following types of bearings are used for the mounting of spindle:

- Preloaded ball bearings
- Preloaded taper roller bearings.
- Hydrostatic journal bearings.
- Oil retaining bearing (Er. M. S. Sehrawat, 2005).

2.6.1.5 Recirculating ball screw and nut assembly:

In the CNC machines, the conventional design of lead screw and its nut assembly is not used because of its lesser power transmission, rate inaccuracy due to backlash and action of higher rate of frictional forces due to sliding motion of the parts.

To avoid the above difficulties, the recirculating ball screw and nut assembly as shown in Fig. (2.3) is used which is very high efficient in working, reversible in operation, lesser wear and tear, longer working life and without stick-slip action.

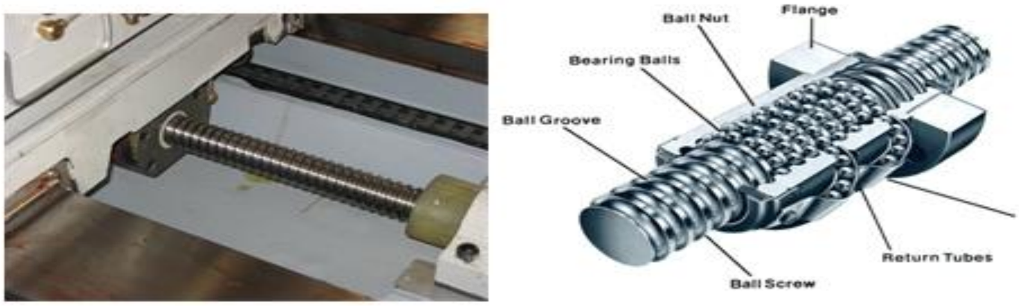


Figure 2. 3 Ball screw

The use of balls gives rolling motion instead of sliding motion which minimizes the frictional forces near to zero value.

Ball screw introduces a series of bearing balls between screw and nut. Rolling of balls in the groove replaces the sliding friction of acme screws. Rolling balls exit from trailing end of nut and picked up by an outside return tube which put it at the leading end of nut.

2.6.2 Part program:

Part program or software is a set of instruction, language, or other such information that control sequence of movement of an NC. The part program is written in coded form as:

1- Binary coded decimal (BCD).
2- Electronic industrial association (EIA).
3- ISO/ASCII code (American standards code for information interchange).

2.6.2.1 CNC Language and Structure

CNC programs list instructions to be performed in the order they are written. They read like a book, left to right and top-down. Each sentence in a CNC program is written on a separate line, called a Block. Blocks are arranged in a specific sequence that promotes safety, predictability and readability, so it is important to adhere to a standard program structure.

Typically, blocks are arranged in the following order:

- Program Start
- Load Tool
- Spindle On
- Coolant On
- Rapid to position above part
- Machining operation
- Coolant Off
- Spindle Off
- Move to safe position
- End program

The steps listed above represent the simplest type of CNC program, where only one tool is used and one operation performed. Programs that use multiple tools repeat steps two through nine for each.

Like any language, the G-code language has rules. For example, some codes are modal, meaning they do not have to be repeated if they do not change between blocks. Some codes have different meanings depending on how and where there are used.

Table 2.1 below list a program for machining a square contour and drills a hole.

Table 2. 1 Machining a square contour and drills a hole

Block	Description	Purpose
%	Start of program.	**Start Program**
O0001 (PROJECT1)	Program number (Program Name).	
(T1 0.25 END MILL)	Tool description for operator.	
N1 G17 G20 G40 G49 G80 G90	Safety block to ensure machine is in safe mode.	
N2 T1 M6	Load Tool #1.	**Change Tool**
N3 S9200 M3	Spindle Speed 9200 RPM, On CW.	
N4 G54	Use Fixture Offset #1.	**Move to Position**
N5 M8	Coolant On.	
N6 G00 X-0.025 Y-0.275	Rapid above part.	
N7 G43 Z1. H1	Rapid to safe plane, use Tool Length Offset #1.	
N8 Z0.1	Rapid to feed plane.	
N9 G01 Z-0.1 F18.	Line move to cutting depth at 18 IPM.	
N10 G41 Y0.1 D1 F36.	CDC Left, Lead in line, Dia. Offset #1, 36 IPM.	**Machine Contour**
N11 Y2.025	Line move.	
N12 X2.025	Line move.	
N13 Y-0.025	Line move.	
N14 X-0.025	Line move.	
N15 G40 X-0.4	Turn CDC off with lead-out move.	
N16 G00 Z1.	Rapid to safe plane.	
N17 M5	Spindle Off.	**Change Tool**
N18 M9	Coolant Off.	
(T2 0.25 DRILL)	Tool description for operator.	

N19 T2 M6 N20 S3820 M3	Load Tool #2. Spindle Speed 3820 RPM, On CW.	
N21 M8 N22 X1. Y1. N23 G43 Z1. H2 N24 Z0.25	Coolant On. Rapid above hole. Rapid to safe plane, use Tool Length Offset 2. Rapid to feed plane.	**Move to Position**
N25 G98 G81 Z-0.325 R0.1 F12. N26 G80 N27 Z1.	Drill hole (canned) cycle, Depth Z-.325, F12. Cancel drill cycle. Rapid to safe plane.	**Drill Hole**
N28 M5 N29 M9 N30 G91 G28 Z0 N31 G91 G28 X0 Y0 N32 G90 N33 M30 %	Spindle Off. Coolant Off. Return to machine Home position in Z. Return to machine Home position in XY. Reset to absolute positioning mode (for safety). Reset program to beginning. End Program.	**End Program**

2.6.3 Machine control unit (MCU):

Every NC machine tool has a main unit, which is known as MCU, consist of some electronic circuits of some electronic circuitry (Hardware) that reads the NC program, interprets it and conversely translates it for mechanical actions of the machine tool.

The MCU may be of three types:

(i) Housed MCU

(ii) Swing around MCU

(iii) Standalone MCU

The MCU is the heart of the CNC system. It is used to perform the following functions:

- To read the coded instructions.
- To decode the coded instructions.
- To implement interpolations (linear, circular, and helical) to generate axis motion commands.
- To feed the axis motion commands to the amplifier circuits for driving the axis mechanisms.
- To receive the feedback signals of position and speed for each drive axis.
- To implement auxiliary control functions such as coolant or spindle on/off and tool change.

There are two sub-units in the machine control unit: the Data Processing Unit (DPU) and the Control Loop Unit (CLU).

a. Data Processing Unit:

On receiving a part program, the DPU firstly interprets and encodes the part program into internal machine codes. The interpolator of the DPU then calculate the intermediate positions of the motion in terms of BLU (basic length unit) which is the smallest unit length that can be handled by the controller. The calculated data are passed to CLU for further work.

b. Control Loop Unit:

The data from the DPU are converted into electrical signals in the CLU to control the driving system to perform the required motions. Other functions such as machine spindle ON/OFF, coolant ON/OFF, tool clamp ON/OFF are also controlled by this unit according to the internal machine codes(Er. M. S. Sehrawat, 2005).

2.6.4 Classification of CNC machine tools:

(1) Based on the motion type:

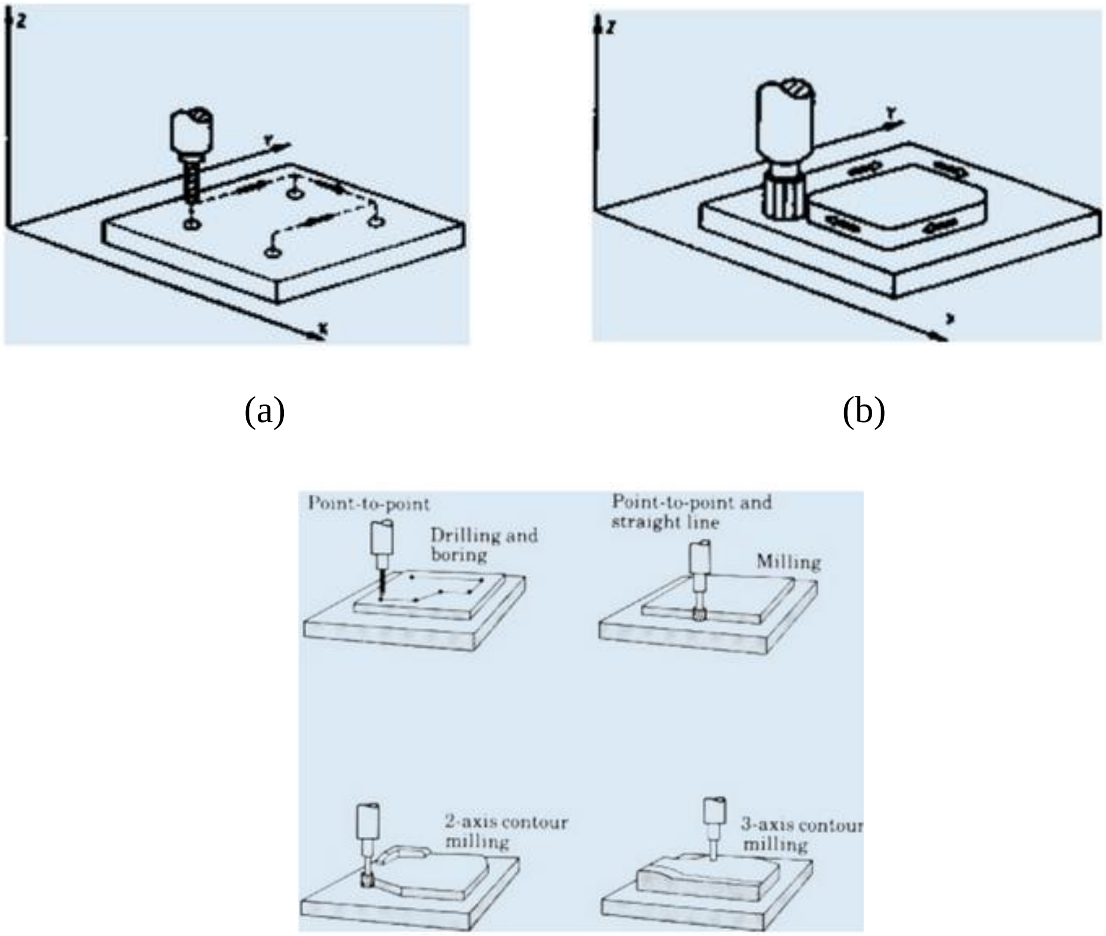
There are two main types of machine tools and control systems required because of the basic differences in the functions of the machines to be controlled. They are known as point-to-point and contouring controls.

a. Point-to-point systems

Some machine tools for example drilling, boring and tapping machines etc, require the cutter and the work piece to be placed at a certain fixed relative positions at which they must remain while the cutter does its work. These machines are known as point-to-point machines as shown in figure (a) and the control equipment for use with them are known as point-to-point control equipment. Feed rates need not to be programmed. In these machine tools, each axis is driven separately. In a point-to-point control system, the dimensional information that must be given to the machine tool will be a series of required position of the two slides. Servo systems can be used to move the slides and no attempt is made to move the slide until the cutter has been retracted back.

b. Contouring systems (Continuous path systems):

Other type of machine tools involves motion of work piece with respect to the cutter while cutting operation is taking place. These machine tools include milling, routing machines etc. and are known as contouring machines as shown in figure (b) and the controls required for their control are known as contouring control. Contouring machines can also be used as point-to-point machines, but it will be uneconomical to use them unless the work piece also requires having a contouring operation to be performed on it. These machines require simultaneous control of axes. In contouring machines, relative positions of the work piece and the tool should be continuously controlled. The control system must be able to accept information regarding velocities and positions of the machines slides. Feed rates should be programmed.



(a) (b)

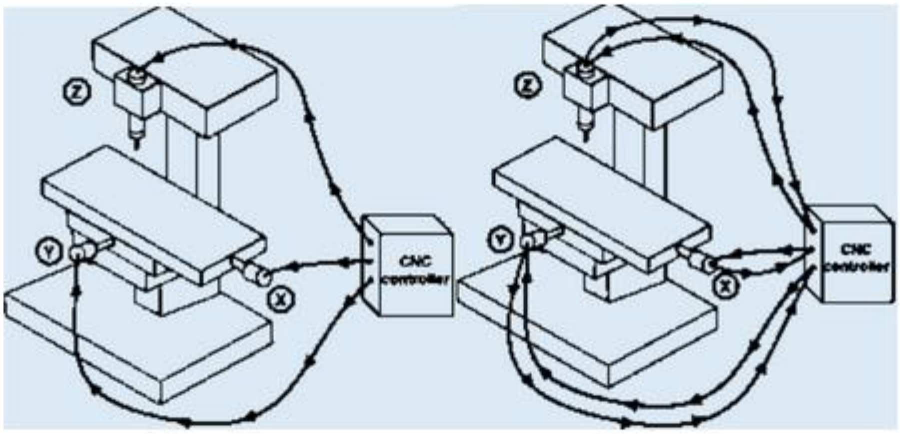
(c)

Figure 2. 4 Point-to-point & contour systems

(2) Based on the control loops:

a. Open loop systems:

Programmed instructions are fed into the controller through an input device. These instructions are then converted to electrical pulses (signals) by the controller and sent to the servo amplifier to energize the servo motors. The primary drawback of the open-loop system is that there is no feedback system to check whether the program position and velocity has been achieved. If the system performance is affected by load, temperature, humidity, or lubrication then the actual output could deviate from the desired output. For these reasons the open –loop system is generally used in point-to-point systems where the accuracy requirements are not critical. Very few continuous-path systems utilize open-loop control.



(a) (b)

Figure 2. 5 (a) open loop system (b) closed loop system

b. Closed loop systems:

The closed-loop system has a feedback subsystem to monitor the actual output and correct any discrepancy from the programmed input. These systems use position and velocity feedback. The feedback system could be either analog or digital. The analog systems measure the variation of physical variables such as position and velocity in terms of voltage levels. Digital systems monitor output variations by means of electrical pulses. To control the dynamic behavior and the final position of the machine slides, a variety of position transducers are employed. Majority of CNC systems operate on servo mechanism, a closed loop principle. If a discrepancy is revealed between where the machine element should be and where it actually is, the sensing device signals the driving unit to make an adjustment, bringing the movable component to the required location. Closed-loop systems are very powerful and accurate because they are capable of monitoring operating conditions through feedback subsystems and automatically compensating for any variations in real-time.

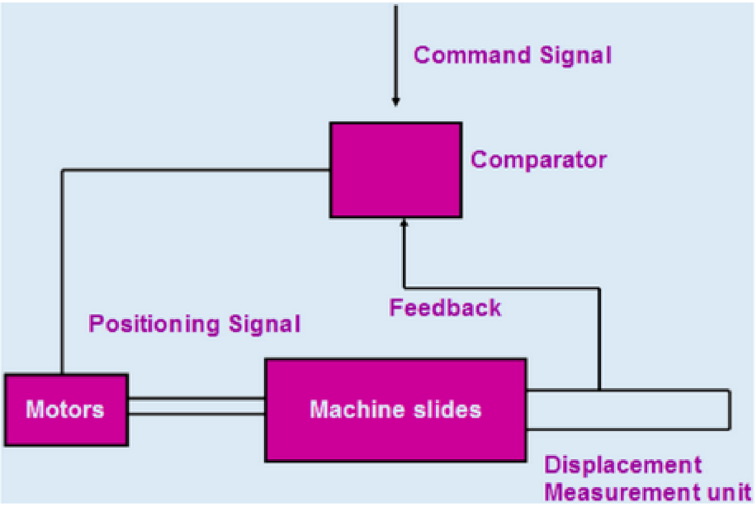


Figure 2. 6 Circuit of feedback system

(3) Based on the number of axes '2, 3, 4 & 5 axes CNC machines.

4. **2& 3 axes CNC machines:**

CNC lathes will be coming under 2 axes machines. There will be two axes along which motion takes place. The saddle will be moving longitudinally on the bed (Z-axis) and the cross slide moves transversely on the saddle (along X-axis). In 3-axes machines, there will be one more axis, perpendicular to the above two axes. By the simultaneous control of all the 3 axes, complex surfaces can be machined.

4. **4 & 5 axes CNC machines:**

4 and 5 axes CNC machines provide multi-axis machining capabilities beyond the standard 3-axis CNC tool path movements. A 5-axis milling centre includes the three X, Y, Z axes, the A axis which is rotary tilting of the spindle and the B-axis, which can be a rotary index table.

(4) Based on the power supply:

Mechanical power unit refers to a device which transforms some form of energy to mechanical power which may be used for driving slides, saddles or gantries forming a part of machine tool. The input power may be of electrical, hydraulic or pneumatic.

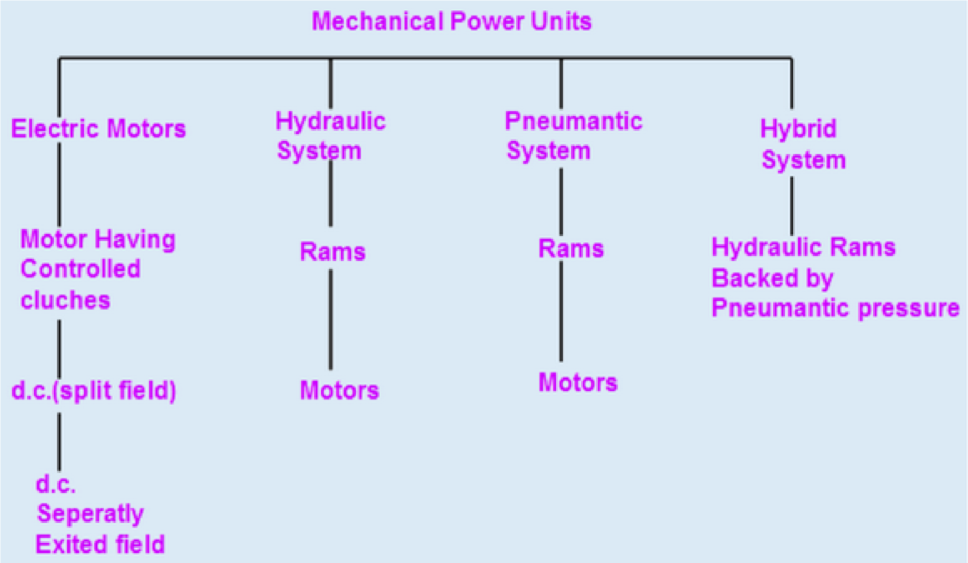


Figure 2. 7 CNC power supply

a. Electric systems:

Electric motors may be used for controlling both positioning and contouring machines. They may be either a.c. or d.c. motor and the torque and direction of rotation need to be controlled. The speed of a d.c. motor can be controlled by varying either the field or the armature supply. The clutch-controlled motor can either be an a.c. or d.c. motor. They are generally used for small machine tools because of heat losses in the clutches. Split field motors are the simplest form of motors and can be controlled in a manner according to the machine tool. These are small and generally run at high maximum speeds and so require reduction gears of high ratio. Separately excited motors are used with control systems for driving the slides of large machine tools.

b. Hydraulic systems:

These hydraulic systems may be used with positioning and contouring machine tools of all sizes. These systems may be either in the form of rams or motors. Hydraulic motors are smaller than electric motors of equivalent power. There are several types of hydraulic motors. The advantage of using hydraulic motors is that they can be very small and have considerable torque. This means that they may be incorporated in servo systems which require having a rapid response.

2.6.5 Machine axes designation

Machine axes are designated according to the "right-hand rule", When the thumb of right hand points in the direction of the positive X axis, the index finger points toward the positive Y axis, and the middle finger toward the positive Z axis.

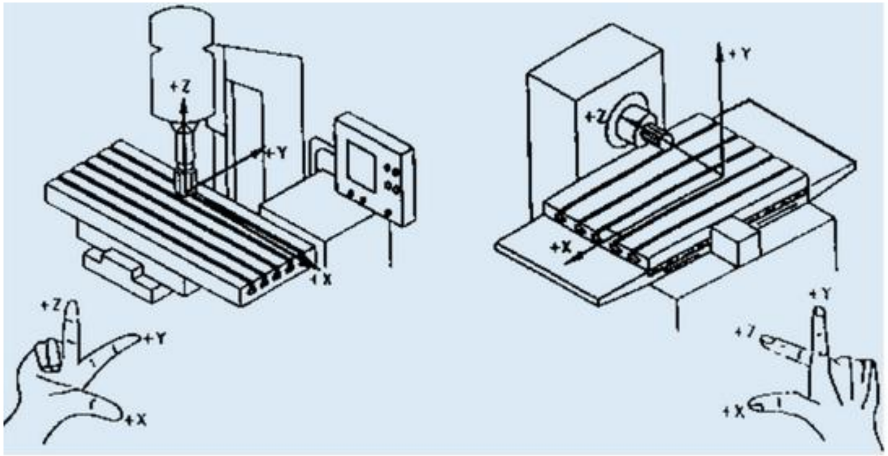


Figure 2. 8 CNC axes according to right-hand rule

2.6.6 Serial communication:

In order to make two devices communicate, whether they are desktop computers, microcontrollers, or any other form of integrated circuit, a method of communication and an agreed-upon language is needed. The most common form of communication between electronic devices is serial communication. Communicating serially involves sending a series of digital pulses back and forth between devices at a mutually agreed-upon rate. The sender sends pulses representing the data to be sent at the agreed-upon data rate, and the receiver listens for pulses at that same rate. This is what’s known as asynchronous serial communication. There isn’t one common clock in asynchronous serial communication; instead, both devices have their own clock and agree on a rate to which to set their clocks.

2.6.6.1 Serial Communication Protocols:

A variety of communication protocols have been developed based on serial communication in the past few decades. Some of them are:

1. SPI – Serial Peripheral Interface: It is a three-wire based communication system. One wire each for Master to slave and Vice-versa, and one for clock pulses. There is an additional SS (Slave Select) line, which is mostly used when to send/receive data between multiple ICs.
2. I2C – Inter-Integrated Circuit: Pronounced eye-two-see or eye-square-see, this is an advanced form of USART. The transmission speeds can be as high as a whopping 400 KHz. The I2C bus has two wires – one for clock, and the other is the data line, which is bi-directional – this being the reason it is also sometimes (not always – there are a few conditions) called Two Wire Interface (TWI). It is a pretty new and revolutionary technology invented by Philips.
3. FireWire – Developed by Apple, they are high-speed buses capable of audio/video transmission. The bus contains a number of wires depending upon the port, which can be either a 4-pin one, or a 6-pin one, or an 8-pin one.

Figure 2. 9 Fire wire

4. Ethernet: Used mostly in LAN connections, the bus consists of 8 lines, or 4 TX/Rx pairs.
5. Universal serial bus (USB): This is the most popular of all. Is used for virtually all type of connections. The bus has 4 lines: VCC, Ground, Data+, and Data-.

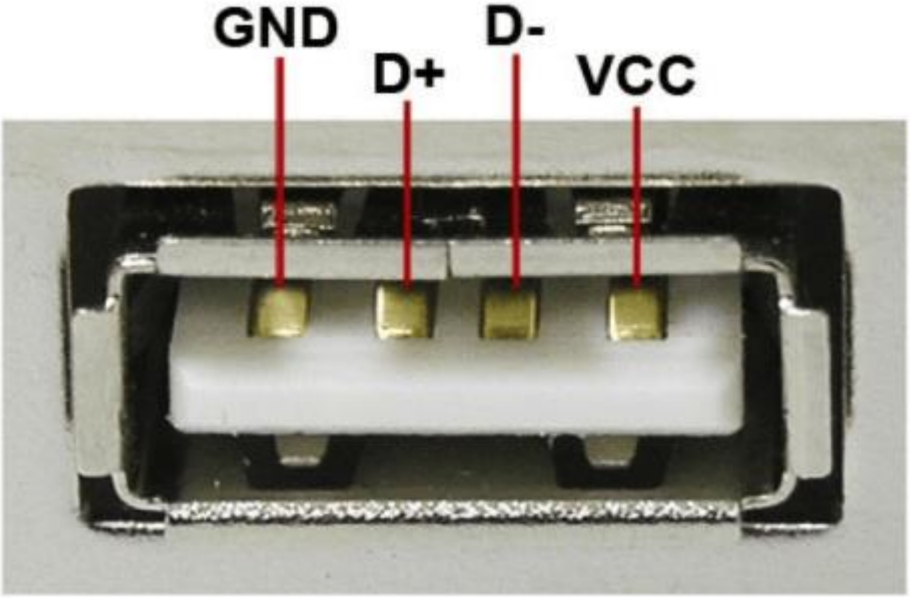


Figure 2. 10 USB Pins

RS-232 – Recommended Standard 232: The RS-232 is typically connected using a DB9 connector, which has 9 pins, out of which 5 are input, 3 are output, and one is Ground. This so-called "Serial" port.

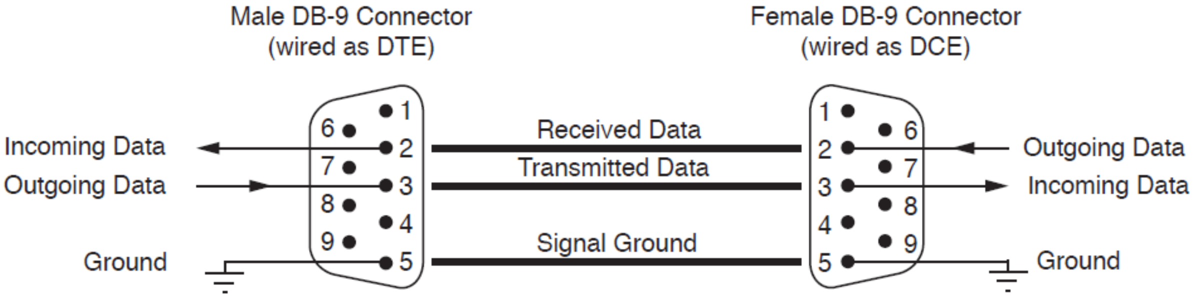


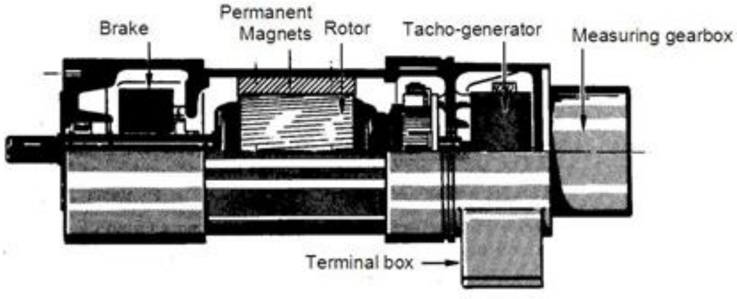
Figure 2. 11 Typical wiring for DTE to DCE connection using DB-9 connectors

2.6.7 Driving System:

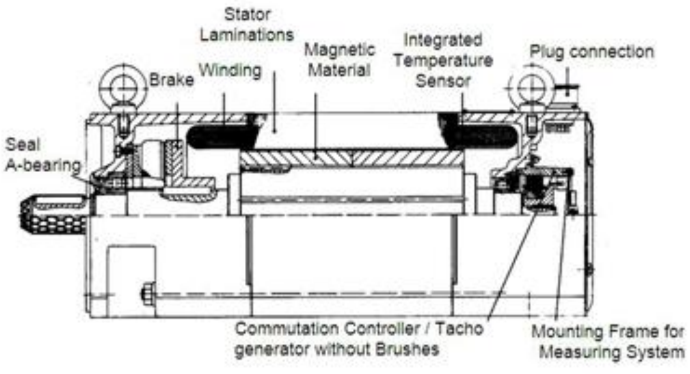
The driving system is an important component of a CNC machine as the accuracy and repeatability depend very much on the characteristics and performance of the driving system. The requirement is that the driving system has to response accurately according to the programmed instructions. This system usually uses electric motors although hydraulic motors are sometimes used for large machine tools. The motor is coupled either directly or through a gear box to the machine lead screw to moves the machine slide or the spindle. Three types of electrical motors are commonly used.

i. DC Servo Motor:

This is the most common type of feed motors used in CNC machines. The principle of operation is based on the rotation of an armature winding in a permanently energized magnetic field. The armature winding is connected to a commutator, which is a cylinder of insulated copper segments mounted on the shaft. DC current is passed to the commutator through carbon brushes, which are connected to the machine terminals. The change of the motor speed is by varying the armature voltage and the control of motor torque is achieved by controlling the motor's armature current. In order to achieve the necessary dynamic behavior it is operated in a closed loop system equipped with sensors to obtain the velocity and position feedback signals.



(a)



(b)

Figure 2. 12 (a) & (b) DC Servo Motor

ii. AC Servo Motor:

In an AC servomotor, the rotor is a permanent magnet while the stator is equipped with 3-phase windings. The speed of the rotor is equal to the rotational frequency of the magnetic field of the stator, which is regulated by the frequency converter. AC motors are gradually replacing DC servomotors. The main reason is that there is no commutator or brushes in AC servomotor so that maintenance is virtually not required. Furthermore, AC servos have a smaller power-to-weight ratio and faster response.

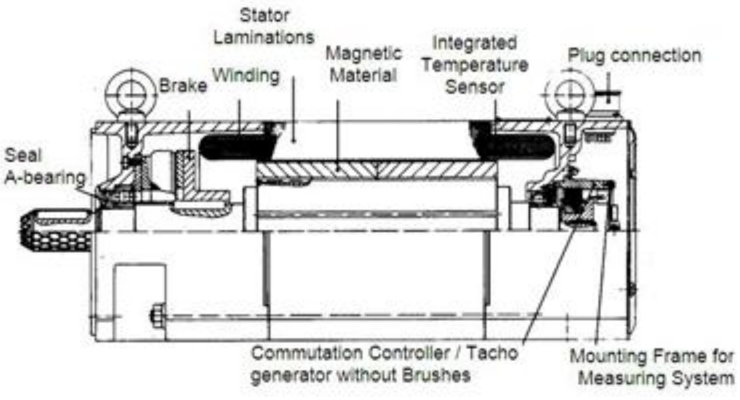


Figure 2. 13 AC Servo Motor

iii. Stepping Motor

A stepping motor is a device that converts the electrical pulses into discrete mechanical rotational motions of the motor shaft. This is the simplest device that can be applied to CNC machines since it can convert digital data into actual mechanical displacement. It is not necessary to have any analog-to-digital converter nor feedback device for the control system. They are ideally suited to open loop systems.

However, stepping motors are not commonly used in machine tools due to the following drawbacks: slow speed, low torque, low resolution and easy to slip in case of overload. Examples of stepping motor application are the magnetic head of floppy-disc drive and hard disc drive of computer, daisy-wheel type printer, X-Y tape control, and CNC EDM Wire-cut machine.

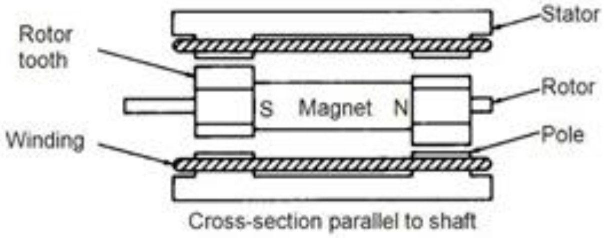


Figure 2. 14 Stepping Motor

2.6.8 Servo Drive:

A servo drive consists of a servo amplifier. The main task of a servo amplifier (also called amplifier, servo controller, or just controller) is the control of the motor current. In addition, ESR servo amplifiers offer a broad spectrum of functionality

While most of the electrical drives are operated at constant speed, a servo drive has a rather "hectic" life. Often it has to accelerate to the rated speed within a few milliseconds only to decelerate a short time later just as quick. And of course the target position is to be reached exactly with an error of a few hundredths of a milli -meter.

Compared to other controlled drives servo drives have the advantage of high dynamics and accuracy, full stall torque, and compact motors with high power density.

Servo drives are used where high dynamics (i. e. fast acceleration and deceleration) and good accuracy at reaching target positions are important. The good control behavior allows the optimal adaptation to the application (e. g. positioning without overshoot). But also the smooth run (due to sinusoidal commutation) and the possibility of exact synchronization of two or more drives open a wide field. Because of their wide speed range servo drives can be used in a huge number of applications.

Servo drives run in large, highly automated installations with several dozens of axes as well as in machines with only a few axes which perhaps operate independently.

The servo amplifier (also called amplifier, servo controller, or just controller) controls the current of the motor phases in order to supply the servo motor with exactly the current required for the desired torque and the desired speed. The essential parts of a servo amplifier are the power section and the control loops.

The power section consists of a mains rectifier, a DC-bus, and a power circuit which supplies the individual motor phases with current.

The control loops (analogue or digital) drive the power circuit and by constantly comparing set point with actual values ensure that the motor keeps exactly to the desired motions even under varying load.

2.6.9 Drive techniques:

There are four types of driving techniques:

a. Wave Stepping (Single Phase Full-Step)

Single phase full-stepping is the most simple of the driving techniques. In full step operation, the motor steps through the normal step angle i.e. 200 step/revolution motors take 1.8 degree steps. Single phase full-step excitation is where the motor is operated with only one phase energized at a time.

Advantages:

- Requires the least amount of power from the drive power supply of any of the excitation modes.
- Contains simpler drive electronics than all other modes.
- Less cost.

Disadvantages:

- Should only be used where torque and speed performance are not important.
- Problems with resonance can preclude operation at some speeds.

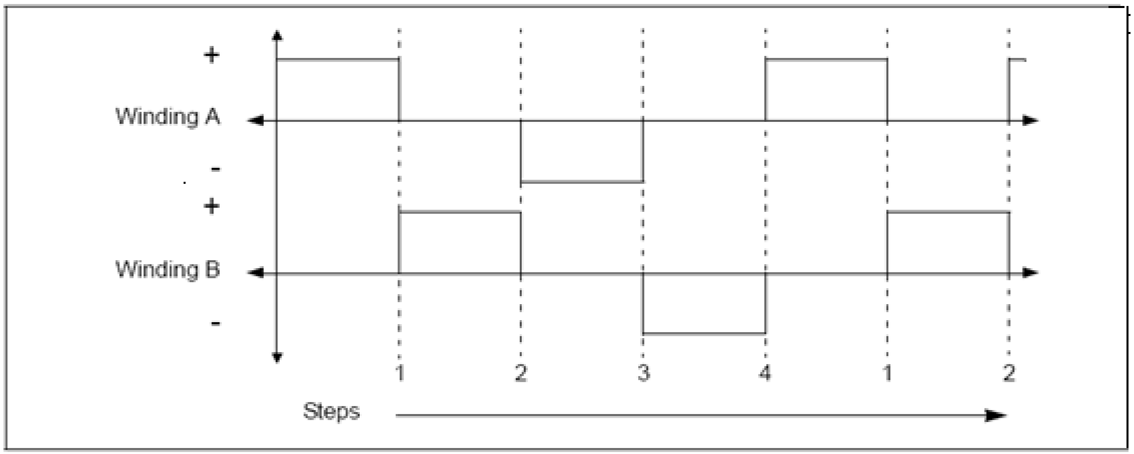


Figure 2. 15 Single Phase Full-Step

b. Full Stepping (Two Phase):

Two phase full-stepping is a drive method where both windings of the motor are always energized. Instead of making one winding off and another on, in sequence, only the polarity of one winding are energized at a time

Advantages:

- This mode provides good torque and speed performance with a minimum amount of resonance problems.
- Provides approximately 50% more torque than single phase full-stepping.

Disadvantages:

- Requires twice the power compared to single phase full-stepping.

- Has an increase in the amount of noise and vibrations when the step-rate equals resonance frequency.

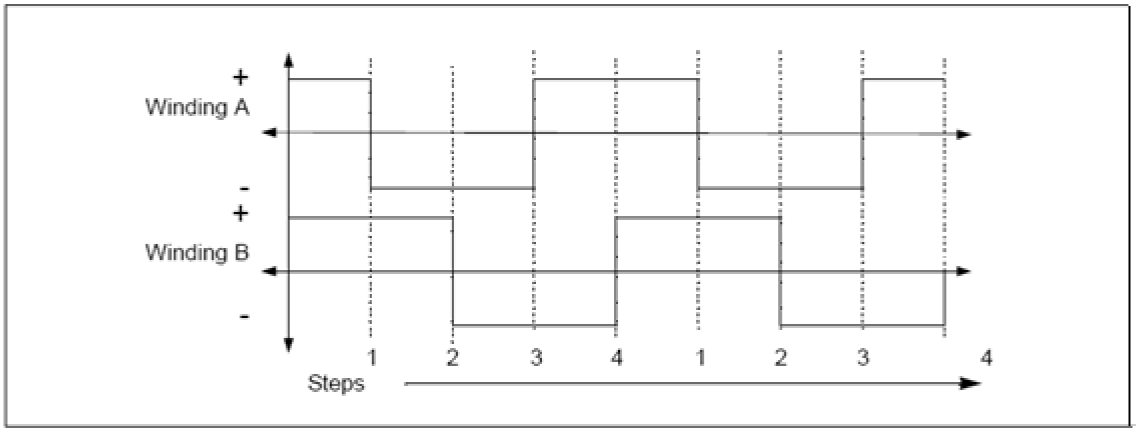


Figure 2. 16 Two Phase Full-Stepping

c. Half stepping:

Half-stepping is alternate single and dual phase operation resulting in steps one half the normal step size. This increases the amount of steps by double compared to full-stepping.

Advantages:

- Has almost no resonance problems
- Operated over a wide range of speeds
- Can drive almost any load

Disadvantages

- Requires more power because of the energizing of the phases
- More complicated drive electronics
- Precision is reduced due to electrical angle changes

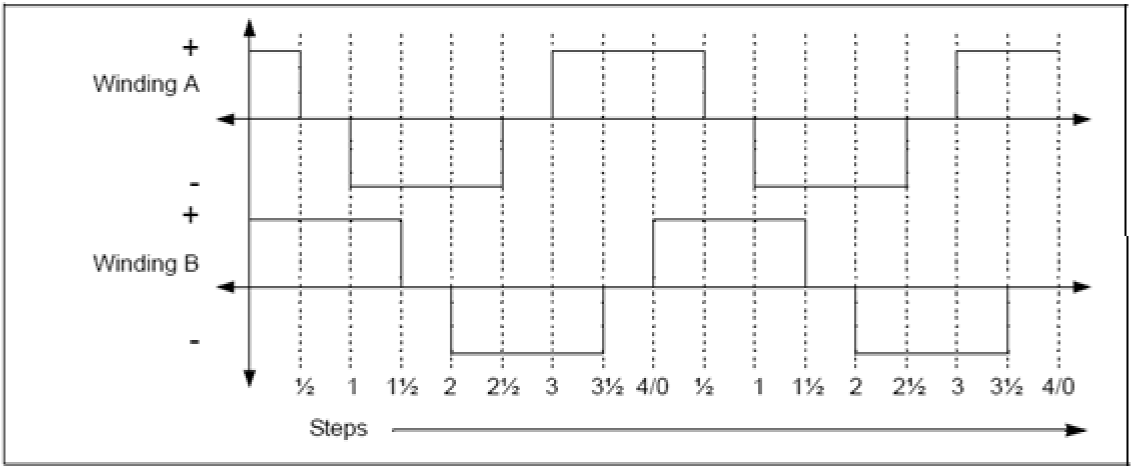


Figure 2. 17 Half-stepping

d. Micro stepping:

Micro-stepping is produced by proportioning the current in the two windings according to sine and cosine functions. Micro-stepping is a way of moving the stator flux of a stepper more smoothly than in full or half step drive modes as stated by Fredrik Eriksson. For practical methods, the current in one winding is kept constant over half of the complete step and current in the other winding is varied as a function of sinθ to maximize the motor torque.

Advantages:

- Smooth movement at low speeds
- Increased step positioning resolution, as a result of a smaller step angle
- Maximum torque at both low and high step-rates

Disadvantages:

- Used only where smoother, low speed motion or more resolution is required
- Low performance at higher speeds

- High cost
- Most complex drive electronic system (James Williams, 2009).

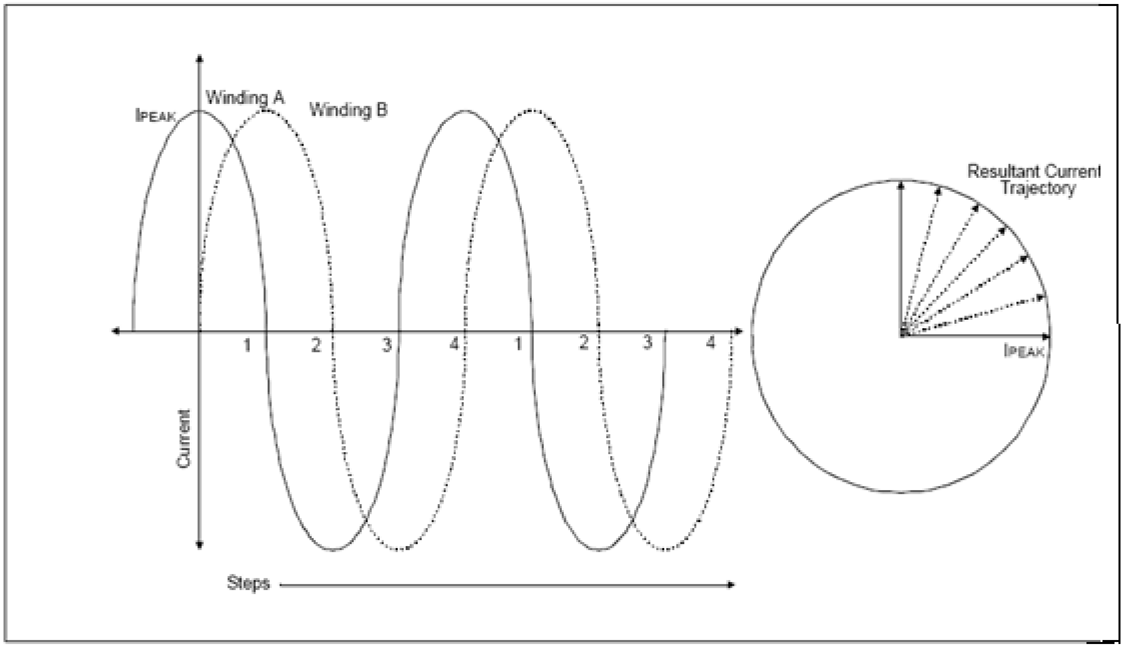


Figure 2. 18 Currents vs. Steps in Windings of Micro-Stepping

2.6.10 Feedback Device:

In order to have a CNC machine operating accurately, the positional values and speed of the axes need to be constantly updated. Two types of feedback devices are normally used positional feedback device and velocity feedback device.

a. Positional Feed Back Devices:

There are two types of positional feedback devices: linear transducer for direct positional measurement and rotary encoder for angular or indirect linear measurement.

1-Linear Transducers

A linear transducer is a device mounted on the machine table to measure the actual displacement of the slide in such a way that backlash of screws; motors, etc. would not cause any error in the feedback data. This device is considered to be of the highest accuracy and also more expensive in comparison with other measuring devices mounted on screws or motors.

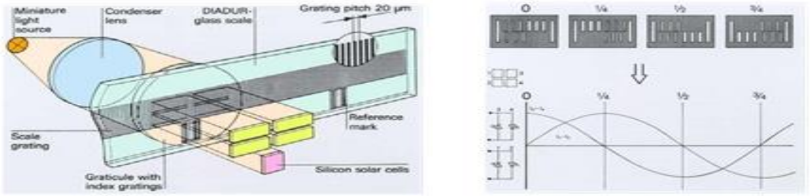


Figure 2. 19 Linear Transducer

2-Rotary Encoders

A rotary encoder is a device mounted at the end of the motor shaft or screw to measure the angular displacement. This device cannot measure linear displacement directly so that error may occur due to the backlash of screw and motor etc. Generally, this error can be compensated for by the machine builder in the machine calibration process.

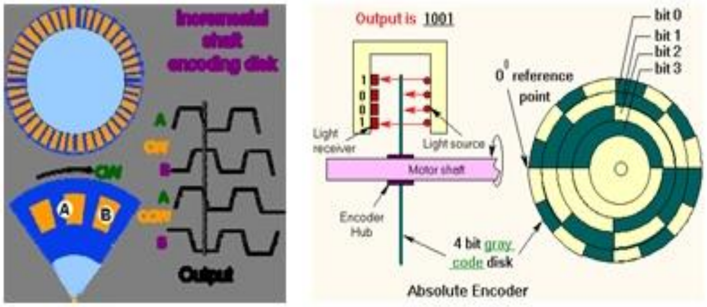


Figure 2. 20 Incremental and Absolute Rotary Encoder

b. Velocity Feedback Device:

The actual speed of the motor can be measured in terms of voltage generated from a tachometer mounted at the end of the motor shaft. DC tachometer is essentially a small generator that produces an output voltage proportional to the speed. The voltage generated is compared with the command voltage corresponding to the desired speed. The difference of the voltages can is then used to actuate the motor to eliminate the error.

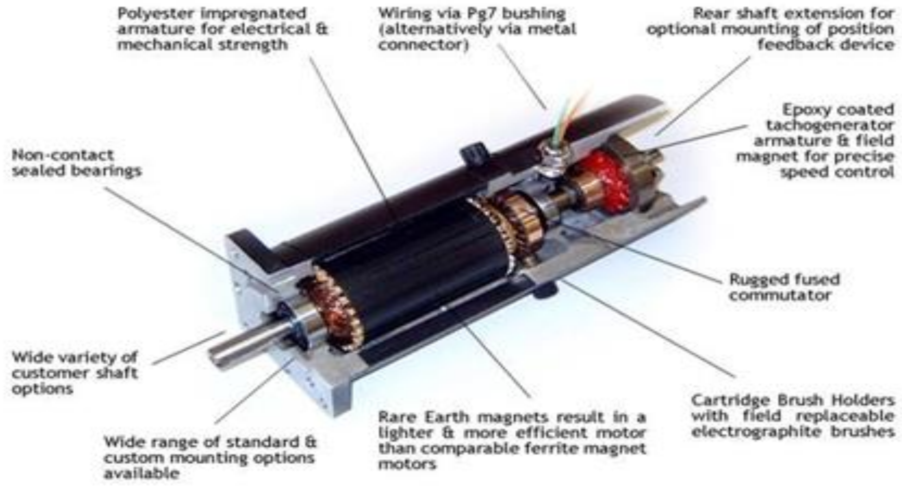


Figure 2. 21 Tacho generator

2.6.11 Programmable Logic Controller (PLC):

A PLC matches the NC to the machine. PLCs were basically introduced as replacement for hard wired relay control panels. They were developed to be reprogrammed without hardware changes when requirements were altered and thus are reusable. Figure 2.22 gives the generalized PLC block diagram.

In the CPU, all the decisions are made relative to controlling a machine or a process. The CPU receives input data, performs logical decisions based upon stored programs and drives the outputs. Connections to a computer for hierarchical control are done via the CPU.

The I/O structure of the PLCs is one of their major strengths. The inputs can be push buttons, limit switches, relay contacts, analog sensor, selector switches, proximity switches, float switches, etc. The outputs can be motor starters, solenoid valves, position valves, relay coils, indicator lights, LED displays, etc.

The field devices are typically selected, supplied and installed by the machine tool builder or the end user. The voltage level of the field devices thus normally determines the type of I/O. So, power to actuate these devices must also be supplied external to the PLC. The PLC power supply is designated and rated only to operate the internal portions of the I/O structures, and not the field devices. A wide variety of voltages, current capacities and types of I/O modules are available.

The principle of operation of a PLC is determined essentially by the PLC program memory, processor, inputs and outputs.

The program that determines PLC operation is stored in the internal PLC program memory. The PLC operates cyclically, i.e. when a complete program has been scanned, it starts again at the beginning of the program. At the beginning of each cycle, the processor examines the signal status at all inputs as well as the external timers and counters and are stored in a process image input (PII). During subsequent program scanning, the processor accesses this process image.

To execute the program, the processor fetches one statement after another from the programming memory and executes it. The results are constantly stored in the process image output (PIO) during the cycle. At the end of a scanning cycle, i.e. program completion, the processor transfers the contents of the process image output to the output modules and to the external timers and counters. The processor then begins a new program scan.

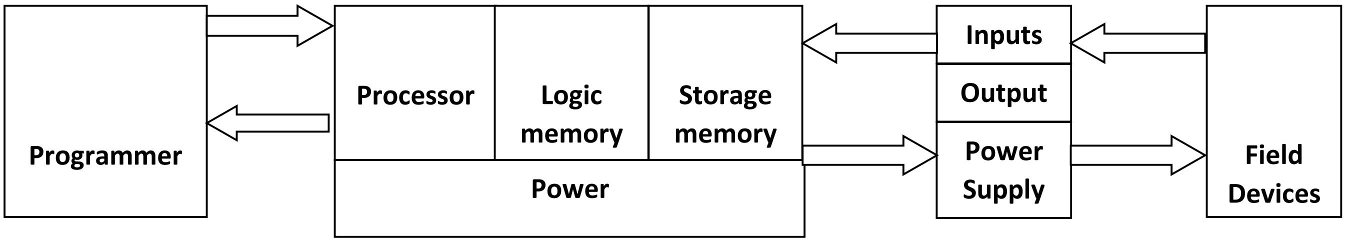


Figure 2. 22 Generalized PLC block diagram

PLC (Programmable Logic Controllers) is an industrial computer used to monitor inputs, and depending upon their state make decisions based on its program or logic, to control (turn on/off) its outputs to automate a machine or a process.

Programmable logic controllers is a digitally operating electronic apparatus which uses a programmable memory for the internal storage of instructions by implementing specific functions such as logic sequencing, timing, counting, and arithmetic to control, through digital or analog input/output modules, various types of machines or processes.

Traditional PLC Applications In automated system, PLC controller is usually the central part of a process control system. To run more complex processes it is possible to connect more PLC controllers to a central computer.

2.6.11.1 Disadvantages of PLC control:

-Too much work required in connecting wires.

- Difficulty with changes or replacements.
- Difficulty in finding errors; requiring skillful work force.
- When a problem occurs, hold-up time is indefinite, usually long.

Advantages of PLC control Rugged and designed to withstand vibrations, temperature, humidity, and noise. Have interfacing for inputs and outputs already inside the controller. Easily programmed and have an easily understood programming language.

2.6.11.2 Major Types of Industrial Control Systems:

Industrial control system or ICS comprise of different types of control systems that are currently in operation in various industries. These control systems include PLC, SCADA and DCS and various others:

a. PLC:

They are based on the Boolean logic operations whereas some models use timers and some have continuous control. These devices are computer based and are used to control various process and equipment within a facility. PLCs control the components in the DCS and SCADA systems but they are primary components in smaller control configurations.

b. DCS:

Distributed Control Systems consists of decentralized elements and all the processes are controlled by these elements. Human interaction is minimized so the labor costs and injuries can be reduced.

c. Embedded Control:

In this control system, small components are attached to the industrial computer system with the help of a network and control is exercised.

d. SCADA:

Supervisory Control and Data Acquisition refers to a centralized system and this system is composed of various subsystems like Remote Telemetry Units, Human Machine Interface, Programmable Logic Controller or PLC and Communications.

2.6.12 Microcontroller:

Microcontroller is a single chip microcomputer made through VLSI fabrication. A microcontroller also called an embedded controller because the microcontroller and its support circuits are often built into, or embedded in, the devices they control. A microcontroller is available in different word lengths like microprocessors (4bit,8bit,16bit,32bit,64bit and 128 bit microcontrollers are available today).

Figure 2. 23 Microcontroller Chip

Microcontrollers is found in all kinds of electronic devices these days. Any device that measures, stores, controls, calculates, or displays information must have a microcontroller chip inside. The largest single use for microcontrollers is in automobile industry (microcontrollers widely used for controlling engines and power controls in automobiles). You can also find microcontrollers inside keyboards, mouse, modems, printers, and other peripherals. In test equipment, microcontrollers make it easy to add features such as the ability to store measurements, to create and store user routines, and to display messages and waveforms.

1. A microcontroller basically contains one or more following components:
   Central processing unit (CPU)
    - Random Access Memory)(RAM)
    - Read Only Memory(ROM)
    - Input/output ports
    - Timers and Counters
    - Interrupt Controls
    - Analog to digital converters
    - Digital analog converters

- Serial interfacing ports
- Oscillatory circuits

2. A microcontroller internally consists of all features required for a computing system and functions as a computer without adding any external digital parts in it.

3. Most of the pins in the microcontroller chip can be made programmable by the user.

4. A microcontroller has many bit handling instructions that can be easily understood by the programmer.

5. A microcontroller is capable of handling Boolean functions.

6. Higher speed and performance.

7. On-chip ROM structure in a microcontroller provides better firmware security.

8. Easy to design with low cost and small size.

2.6.12.1 Microcontroller structure

The basic structure and block diagram of a microcontroller is shown in the figure (2.24).

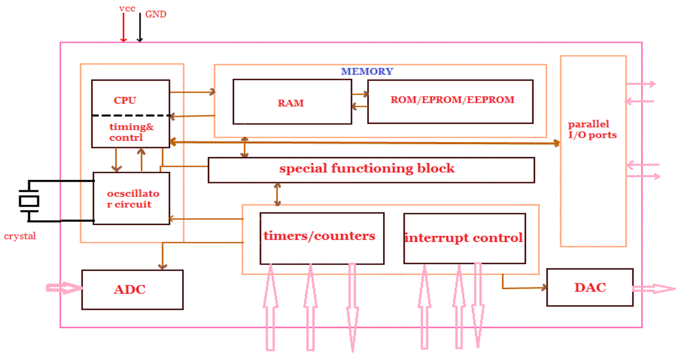


Figure 2. 24 Microcontroller Structure

a. CPU:

CPU is the brain of a microcontroller .CPU is responsible for fetching the instruction, decodes it, and then finally executed. CPU connects every part of a microcontroller into a single system. The primary function of CPU is fetching and decoding instructions. Instruction fetched from program memory must be decoded by the CPU.

b. Memory:

The function of memory in a microcontroller is same as microprocessor. It is used to store data and program. A microcontroller usually has a certain amount of RAM and ROM (EEPROM, EPROM, etc.) or flash memories for storing program source codes.

c. Parallel input/output ports:

Parallel input/output ports are mainly used to drive/interface various devices such as LCD’S, LED’S, printers, memories, etc. to a microcontroller.

d. Serial ports:

Serial ports provide various serial interfaces between microcontroller and other peripherals like parallel ports.

e. Timers/counters:

This is the one of the useful function of a microcontroller. A microcontroller may have more than one timer and counters. The timers and counters provide all timing and counting functions inside the microcontroller. The major operations of this section are perform clock functions, modulations, pulse generations, frequency measuring, making oscillations, etc. This also can be used for counting external pulses.

f. Analog to Digital Converter (ADC):

ADC converters are used for converting the analog signal to digital form. The input signal in this converter should be in analog form (e.g. sensor output) and the output from this unit is in digital form. The digital output can be used for various digital applications (e.g. measurement devices).

g. Digital to Analog Converter (DAC):

DAC perform reversal operation of ADC conversion. DAC convert the digital signal into analog format. It usually used for controlling analog devices like DC motors, various drives, etc.

h. Interrupt control:

The interrupt control used for providing interrupt (delay) for a working program .The interrupt may be external (activated by using interrupt pin) or internal (by using interrupt instruction during programming).

i. Special functioning block:

Some microcontrollers used only for some special applications (e.g. space systems and robotics) these controllers containing additional ports to perform such special operations. This considered as special functioning block.

2.6.13 Display Unit:

The Display Unit serves as an interactive device between the machine and the operator. When the machine is running, the Display Unit displays the present status such as the position of the machine slide, the spindle RPM, the feed rate, the part program, etc. In an advanced CNC machine, the Display Unit can show the graphics simulation of the tool path so that part program can be verified before the actually machining. Much other important information about the CNC system can also displayed for maintenance and installation work such as machine parameters, logic diagram of the programmer controller, error messages and diagnostic data.

2.6.14 Tools for CNC machine:

Special care has to be taken for the tooling of CNC machines as compared to the conventional machines, because these are used for high rate of metal removal to minimize the production cycle time. Fig. (2.23) shows CNC cutting tools.

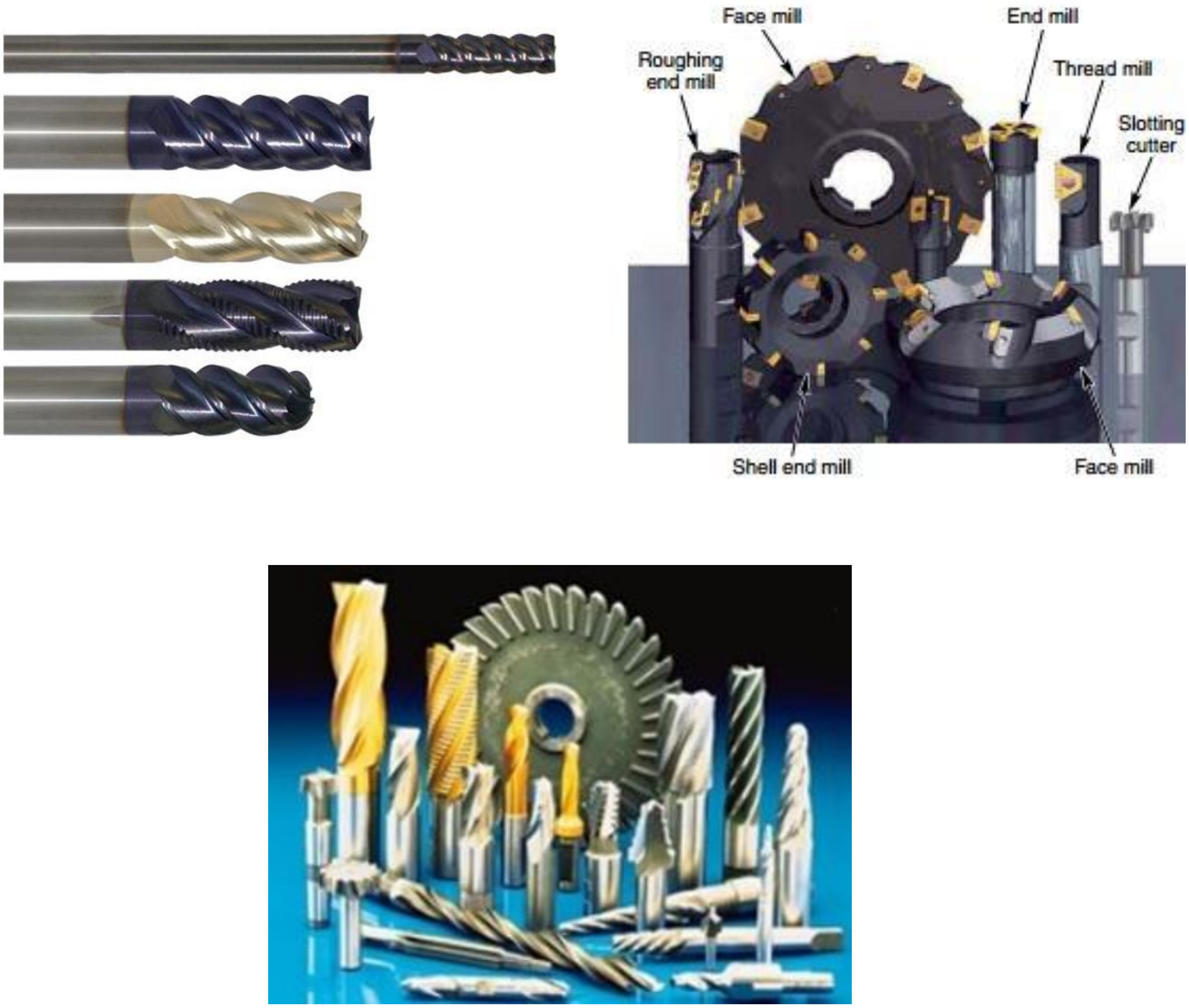


Figure 2. 25 CNC Cutting tools

2.7 Laser CNC technology:

Laser, is electromagnetic radiation with wavelength ranging from the ultraviolet to infrared range. Laser can deliver very low (~ mW) to extremely high (1-100kW) focused power with a precise spot size/dimension and spatial/temporal distribution on a given substrate through any intervening medium. As a result, lasers have wide-ranging of applications in different materials processing (J.D.Majumdar, 2013).

2.7.1 Types of lasers used in material processing:

(1) Solid-state (crystal or glass) lasers, (2) Gas lasers, (3) Liquid lasers (Dye lasers), (4) Chemical lasers, (5) Semiconductor lasers, (6) Color-center lasers (O. Svelto, 1980).

2.7.1.1 Solid-State Lasers:

The term solid-state laser is usually reserved for those lasers having their active medium either an insulating crystal or glass. Solid-state lasers often use as their active species impurity ions introduced into an ionic crystal. Usually the ion belongs to one of the series of transition elements in the periodic table. The transitions for laser action involve states belonging to the inner unfilled shells. The common solid state lasers are Ruby laser emit at λ=694.3 nm with a power from MW to GW, Nd:YAG laser emit at λ =1.06 μm with a power range from hundreds Watt up to MW, and Nd:glass emit at λ = (1.054-1.062) μm with a peak power of more than TW (O. Svelto, 1980).

2.7.1.12 Gas lasers:

They are lasers that utilize a gaseous material as the active laser medium, generally have a wide variety of characteristics. The medium is homogeneous, there is no possibility of damage to the active medium. Some gas lasers emit power below 1 m W, but other gas lasers emit power of the order of kilowatts. Some lasers can emit continuous beam for years, others emit pulses lasting a few nanoseconds. Their wavelengths range from deep in the vacuum ultraviolet through the visible and infrared. Examples of gas lasers are H_eN_e laser emit at λ =632.8 nm and Co_2 laser emit at 10.6 μm (John, 1997).

2.7.1.3 Liquid Lasers (Dye Lasers)

The liquid lasers are those in which the active medium consists of solutions of certain organic dye compounds in liquids such as ethyl alcohol, methyl alcohol, or water. These dyes usually belong to one of the following classes: (i) Polymethine dyes (0.7-1 µm), (ii) Xanthene dyes (0.5-0.7 µm), (iii) Coumarin dyes (0.4-0.5 µm), and (iv) Scintillator dyes (λ<0.4 µm). By virtue of their wavelength tenability, wide spectral coverage, and simplicity, organic dye lasers are playing an increasingly important role in various fields of application (from spectroscopy to photochemistry) (O. Svelto, 1980).

2.7.1.4 Chemical Lasers

A chemical laser is usually defined as one in which the population inversion is ‘directly’ produced by a chemical reaction between gaseous elements. In this case, a large proportion of the reaction energy is left in the form of vibration energy of the molecules. The laser transitions are therefore often of vibrational-rotational type. These lasers are interesting for two main reasons: (i) They provide an interesting example of direct conversion as chemical energy into electromagnetic energy (ii) Since the amount of energy available in a chemical reaction is very large, one can expect high output powers. An example of chemical lasers is HF laser emits in the 2.6-3.3 µm and the atomic iodine laser emit at 1.315 nm (O. Svelto, 1980).

2.7.1.5 Semiconductor Lasers

Semiconductor lasers (also called diode lasers or injection lasers) uses small chip of semiconducting material as an active medium. The most common semiconductor laser material is the alloy aluminum.

A semiconductor laser uses special properties of the transition region at the junction of a p-type semiconductor in contact with an n-type semiconductor, and emission wavelengths from the blue to the mid-infrared (John, 1997).

2.7.1.6 Color-Center Laser

A number of different types of color-centers are now being used as the basis of efficient, optically pumped lasers with broad tunability in the near infrared. At present, color-center lasers allow operation over the wavelength range 0.8-3.3 µm. On a scale of increasing wavelength, these lasers thus take over just where the organic dyes give up. An examples of color-center are KCI:Li (λ =2.5-2.9 µm) and Rbcl:Li (λ =2.7-3.3 µm) (O. Svelto, 1980).

Figure 2.26 presents a brief overview of the applications of lasers in different fields with diverse objectives. (J.D.Majumdar, 2013).

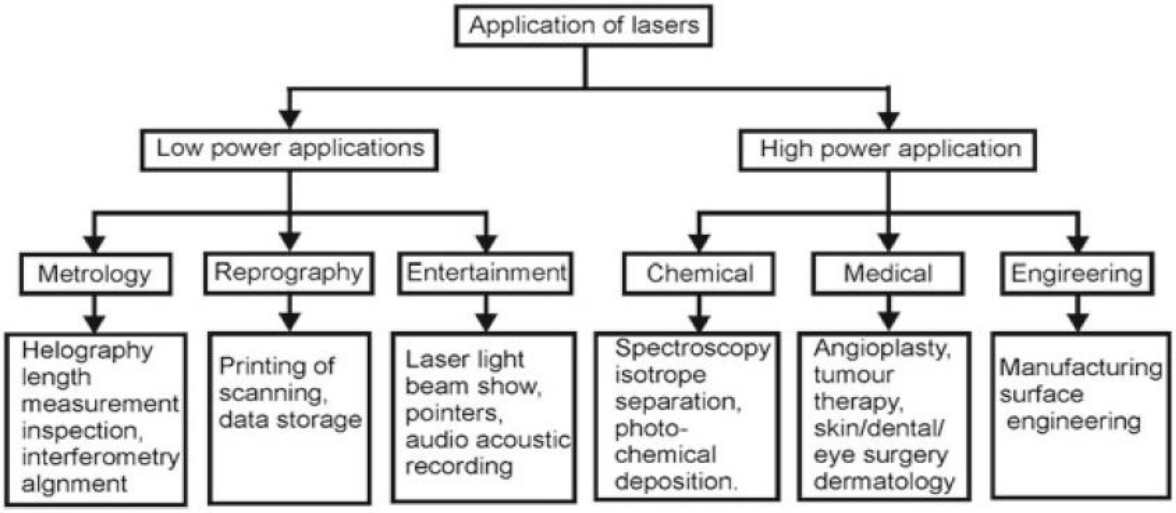


Figure 2. 26 Applications spectrum of lasers

Figure 2.27 shows a general classification of the laser assisted fabrication techniques. In general. Application of laser to materials fabrication can be grouped into two major classes (a) applications requiring limted energy/power and causing limited microstructural changes only within a small volume/area without change of state and (b) applications requiring substantial amount of energy to include the change in state and phase transformation in large volume/area.(J.D.Majumdar, 2013).

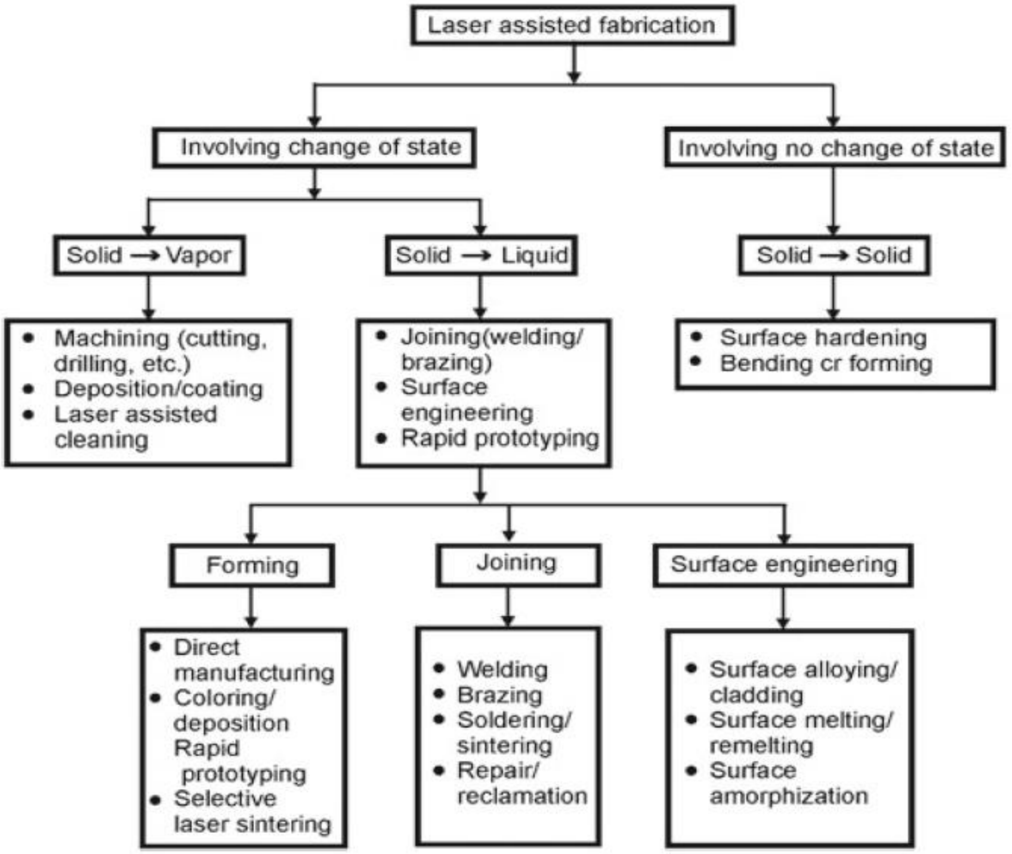


Figure 2. 27 General classification of laser assisted fabrication of materials for engineering applications

2.7.2 Advantages of laser:

1- The ability to focus the beam to a small size, thereby attaining a high intensity and highly localized heating source with minimal effect on surround areas. Spot sizes may vary approximately from 0.001 to 10 mm.

2- The case with which the beam power can be controlled by regulating the current through the electric discharge.

3- Minimal contamination of the process.

4- Ability to manipulate the beam into ordinarily inaccessible areas using mirrors and fiber optics.

5- Minimal heat-affected zone and distortion.

6- Noncontact nature of the process.

2.7.3 Disadvantages of lasers:

1- Relatively high capital cost of equipment.

2- High reflectivity of laser beam on materials.

3- Low efficiency of lasers.

4- Energy waste by beam dumping when the laser is not used continuously.(E.kannatey, 2009)

2.8 Literature review:

To get along with the development and rapid growth of the manufacturing sector. A portable CNC lasers machines have been designed and used in a wide range of lasers applications. Some of the resent CNC systems are reviewed in this part of research.

Jayson P. Rogelio has presented in 2015 a development of a PC-based controller for the 3-axis computer numerically-controlled CNC laser machine. This includes the use of an MK-II motion controller board in controlling the three Ezi-servo stepper motors and in enabling the laser output from the Synrad Firestar f201. The laser power output was controlled using a developed PWM controller. The machine was tested both in functional and performance testing. In terms of performance, it can cut mild steel and stainless steel with thickness of 2 mm and 1 mm, respectively. PLT extension file was used for the g-code toolpath of the CNC laser machine system. Figure 2.28 shows GUI for the Laser power controller.

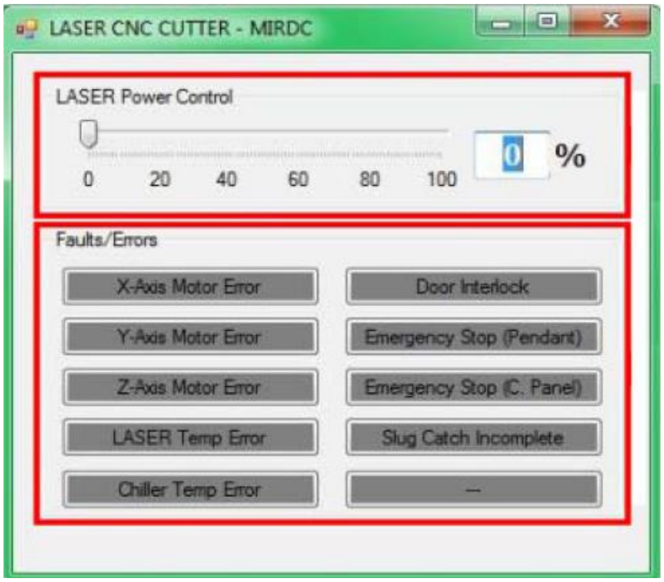


Figure 2. 28 GUI for the Laser power controller

In 2015 Ravi Kumar R also has designed a portable Laser bot, Arduino powered, portable laser cutter that can cut on various surface, Aluminum Foil, Foam, Plywood, etc. depending on the intensity of laser Diode. The quality of laser cut is of the all most importance in laser cutting process.

Laser bot is a low cost machine capable of positioning the laser module in three axes, using 1 W 450 nm laser Diode, achieving planar positioning and actuating the laser up and down vertically. The machine has designed to be highly precise, compact and easy to operate. This has inspired by the mechanism adopted by the X-Y plotter. And so, this uses an X-Y mechanism where in the necessary drive has given by the drag chain, powered by stepper motors. This has actuated by means of electronic components such as Arduino, Raspberry Pi and software's such as GRBL converter and Arduino IDE for the G-code conversion and programming respectively. The G-codes are sent to the Arduino, wherein it converts the G-codes into movements made by the actuation of stepper motor.

- Components of laser bot:

a. Wooden frame:

Used for support, having dimensions-349x32x18mm shorter bar and 483x44x18 longer bar (with 5mm holes).

b. Steel rods:

Facilitate swift movement within the workspace.

c. Electronics:

The electronics consist of Arduino UNO (microcontroller). The Arduino Uno can be powered via the USB connection or with an external power supply, the power source is selected automatically.

d. Bearing and pulleys:

Linear type of bearings was used to provide smooth movement once coupled with the device and the axial type bearing is to act as an idler pulley. The pulley used is GT2 type.

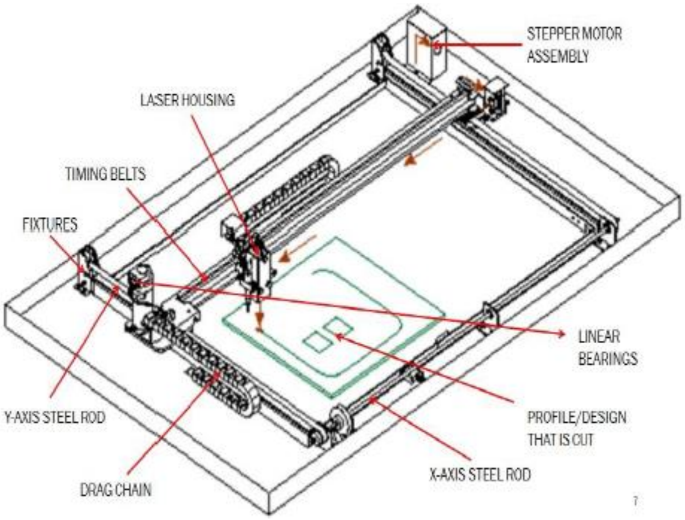


Figure 2. 29 The X-Y mechanism

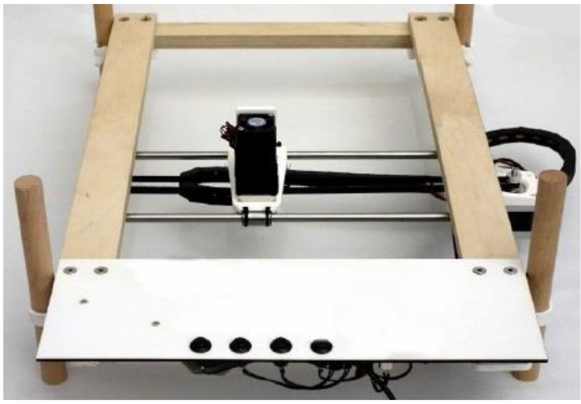


Figure 2. 30 The portable laser cutter

A CNC prototype machine has been designed, with three Cartesian axes, with 600 mm of length both X and Y axes and 100 mm of length Z axis.

The components that was used: (1) as mechanical drive, three stepper motors with holding torque of 10 kgf.cm, 8W of power per phase, 1.8^o step angle and positioning precision higher than 95%; (2) as end effector, an universal DC machine, with nominal power of 150 W and nominal speed of 35000 RPM, non-specified precision; (3) a 1045 steel threaded rod as rotational to translational mechanic converter, with 3 mm step and precision higher than 95%; (4) bronze and polyacetal nuts. The machine's general characteristics are listed in table 2.1.

Table 2.2 the machine's general characteristics

Travel on axis X and Y	480 mm
Travel on axis Z	100 mm
Maximum holding torque on axis	10 kgf.cm
Motor wiring	Bipolar
Bipolar motor parameters	L=0.020 H, R= 4 Ω
Resolution	200 steps per revolution
Driving mode	Half step

Thread Rod	Trapezoidal, 14 mm diameter, 3 mm step
Nut	Polyacetal e Brass
End effector	Universal machine, 150 W, 35000 rpm. Variable speed, controlled by a phase controlled TRIAC
Mandrel	manual tool change, 3.2 mm diameter

Although interfacing with peripherals has been connected through a serial port has massively documented in various programming languages, the LabVIEW IDE was chosen.

A microcontroller 18F2550 was communicated through USB at full speed 12 Mbps. To drive motors winding, four command lines were used to control a double integrated H bridge, physically implemented by the integrated circuit L298. (Paulo A., 2012).

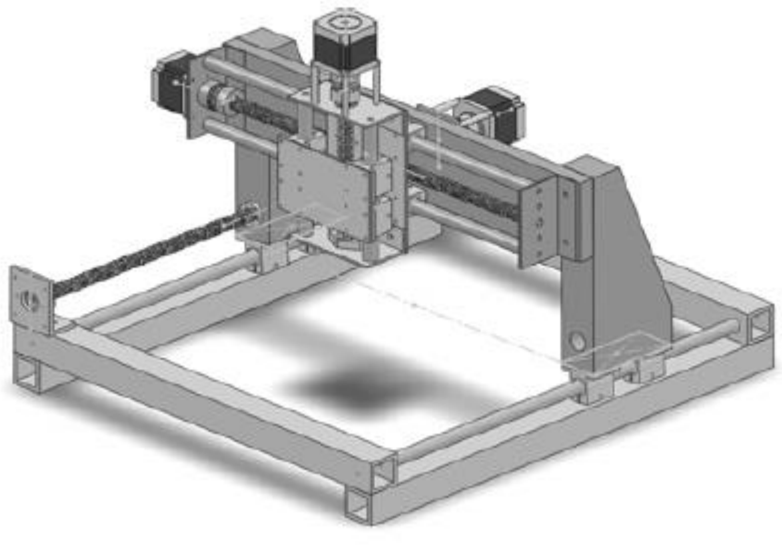


Figure 2. 31 virtual 3D image of the projected machine

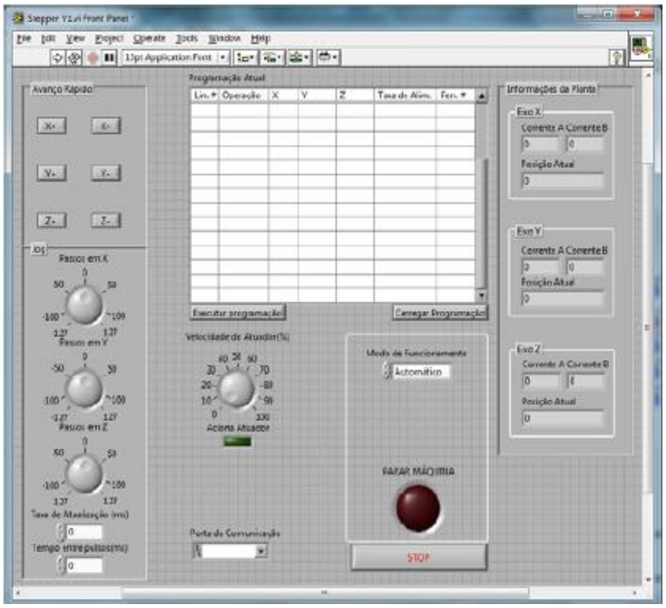


Figure 2. 32 User interface of the LabVIEW program

Sergej N. (2014) proposed an approach of building a portable CNC kernel based on platform independent libraries. Open architecture CNC system offers levels of abstraction in the kernel for implementing various HMIs. Accepting different part program language versions and using different fieldbuses. An example of adapting cross-platform CNC kernel for multi-channel and multi-axis machine tool is illustrated.

Figures 2.33 and 2.34 show the variants of arranging the control system and sketch of the machine tool.

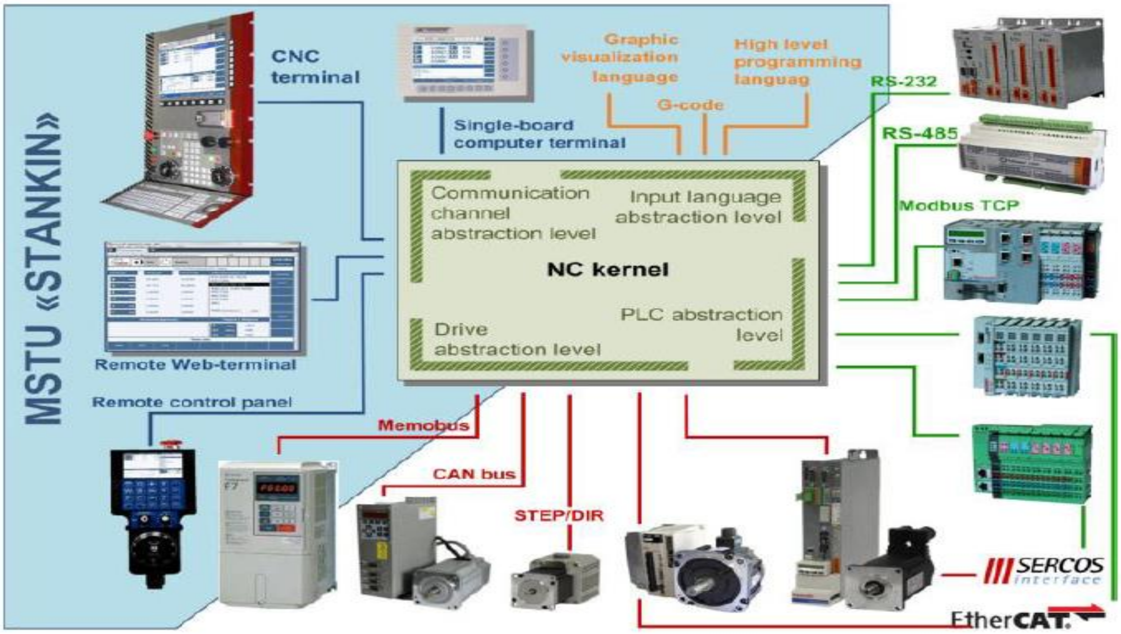


Figure 2. 33 Variants of arranging the control system

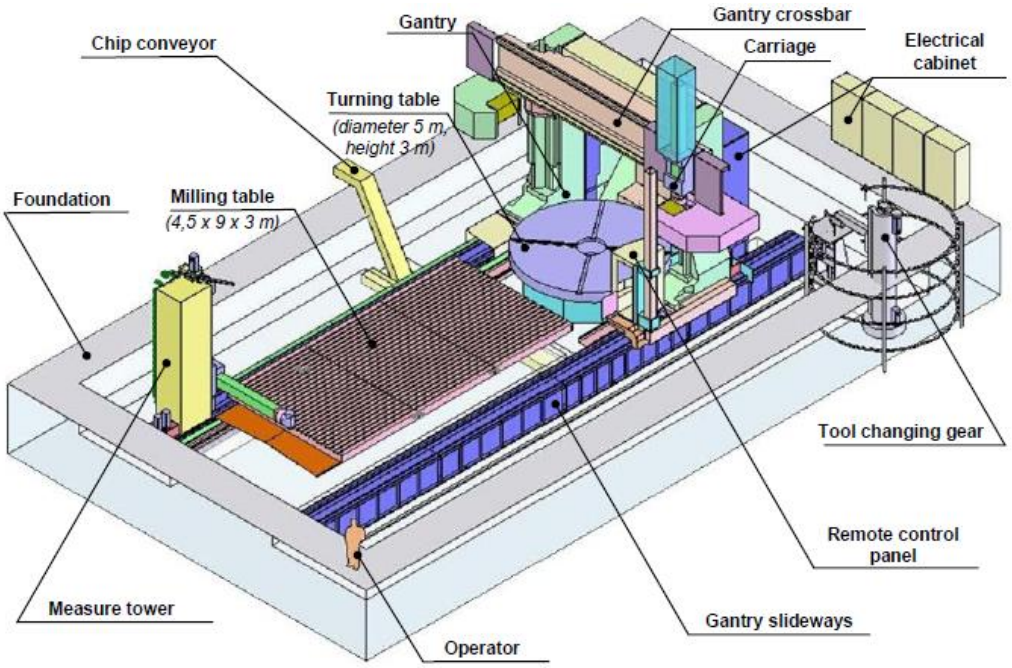


Figure 2. 34 Sketch of the machine tool

In a study to build specialized CNC systems for non-traditional processes, the tasks of controlling non-traditional processes go beyond the capability of classical open CNC systems which did not allow them to be used to solve the new range of tasks. An underlying computer platform enabling on its base specialized CNC systems for non-traditional processes has been created. A limited and at the same time extensible set of software and hardware components that implement the new processing technologies has been defined. And a solution matrix for the subsequent synthesis of specialized CNC systems has been built. The procedure of the synthesis of specialized CNC systems is illustrated by an example of a five-axis water jet cutting machine and a machine for selective laser sintering. Figure 2.35 shows the hardware-software complex for selecting laser sintering. (Georgi M. Martinov, 2014).

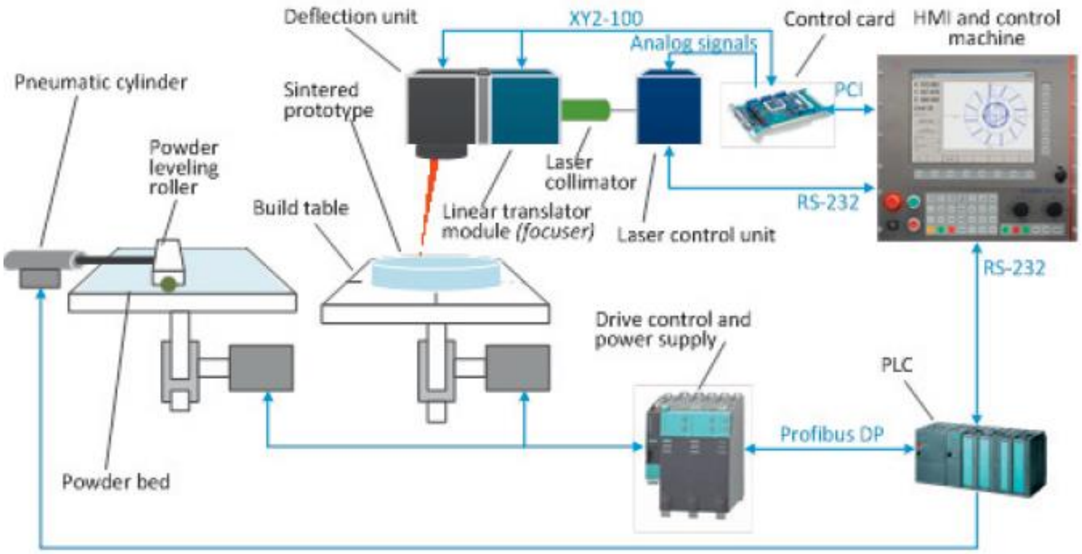


Figure 2. 35 Hardware-software complex for selecting laser sintering

Malica kovjanic in 2014 designed lab 3-axis CNC milling machine, the basic module of the support structure including the drive systems and the measuring systems, module of the main spindle and the control unit have presented. The goal of the research was to develop their own hardware and software system of the control unit that enable the direct entry and recognition of G-code according to ISO 6983. Figure 2.36 shows the 3-axis CNC machine.

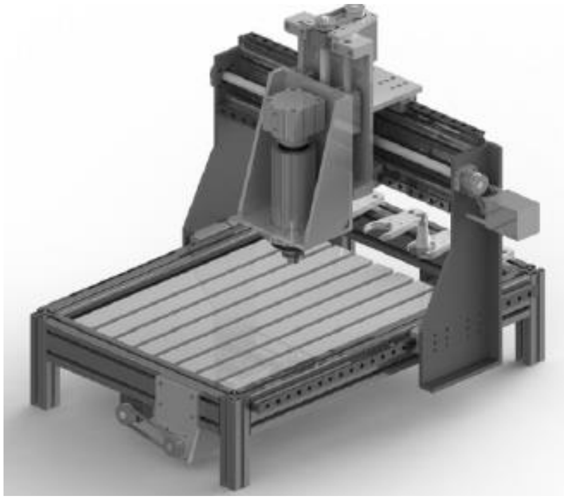


Figure 2. 36 The 3-axis CNC machine

Ersan in 2014 in an industrial project at Uludag University has optimized the process with integrated topology optimization has been used very successfully. In this project, the side walls of a large CNC portal milling machine made of cast-iron have been optimized by using Ansys software. The goal was to reduce the weight without reducing the strength and stiffness for the side walls of CNC milling machine. Finally, the objective of light weight structure was achieved and its prototype was manufactured successfully. The figure (2.37) shows the study diagrams.

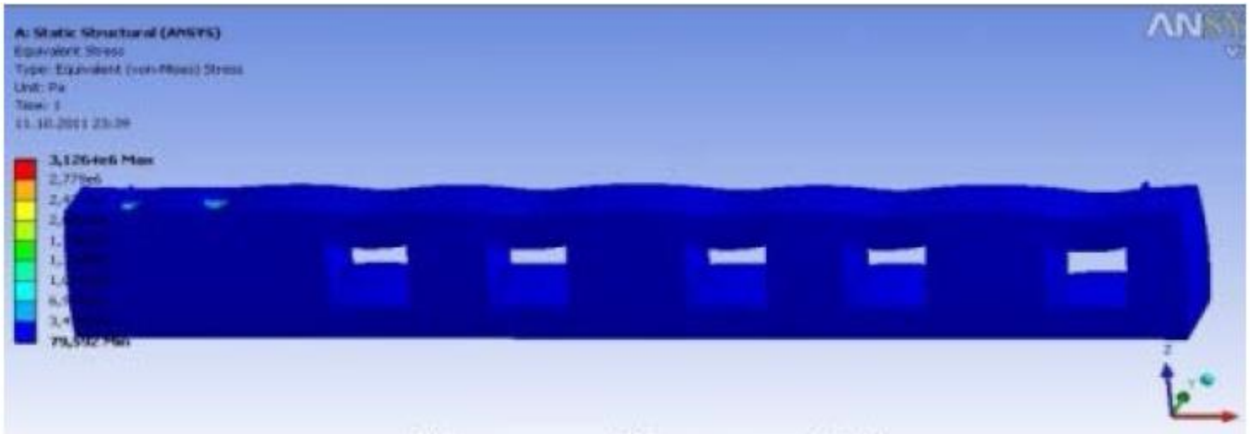


Figure 2. 37 Stress analysis results for initial design

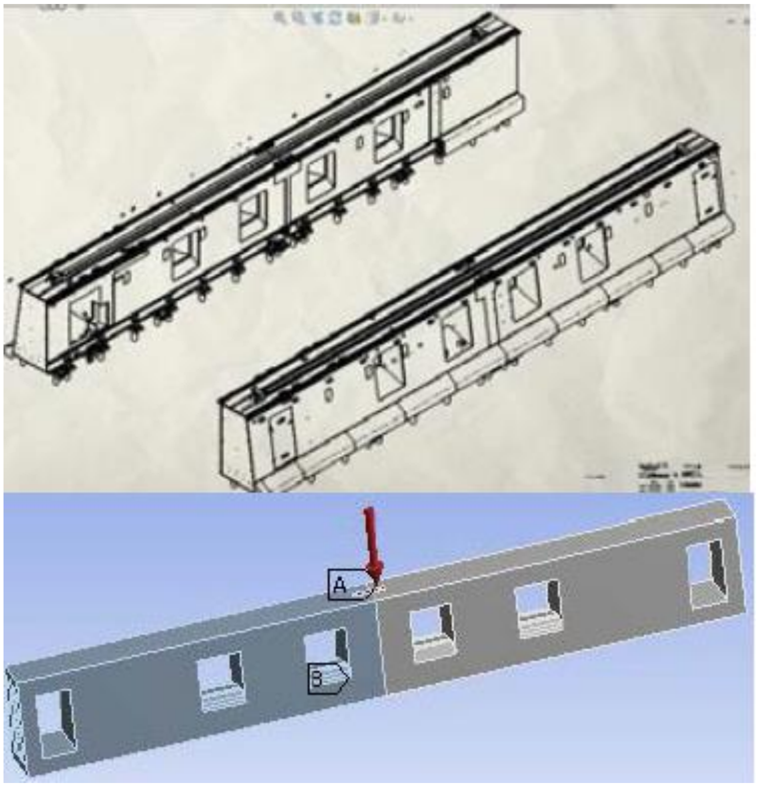


Figure 2. 38 Second design for side wall

In 2012 D. K. Krishna has attempted to control the axes motion of CNC machine by controlling the speed of both DC as well as stepper motors. A PC-to-Motor interface and driver circuit board has been designed and developed for the present system. The software of the system has been developed using LabVIEW-based graphical programming language. LabVIEW provides the flexibility of integration of data acquisition software/hardware with the motion control applications software for automated test and measurement applications. The control system proposed in this paper has the capability to control four axis of motion using DC motors or two axis of motion using stepper motors. Figure 2.39 shows block diagram of 2-axis stepper motor motion control. (D. K. Krishna, 2012)

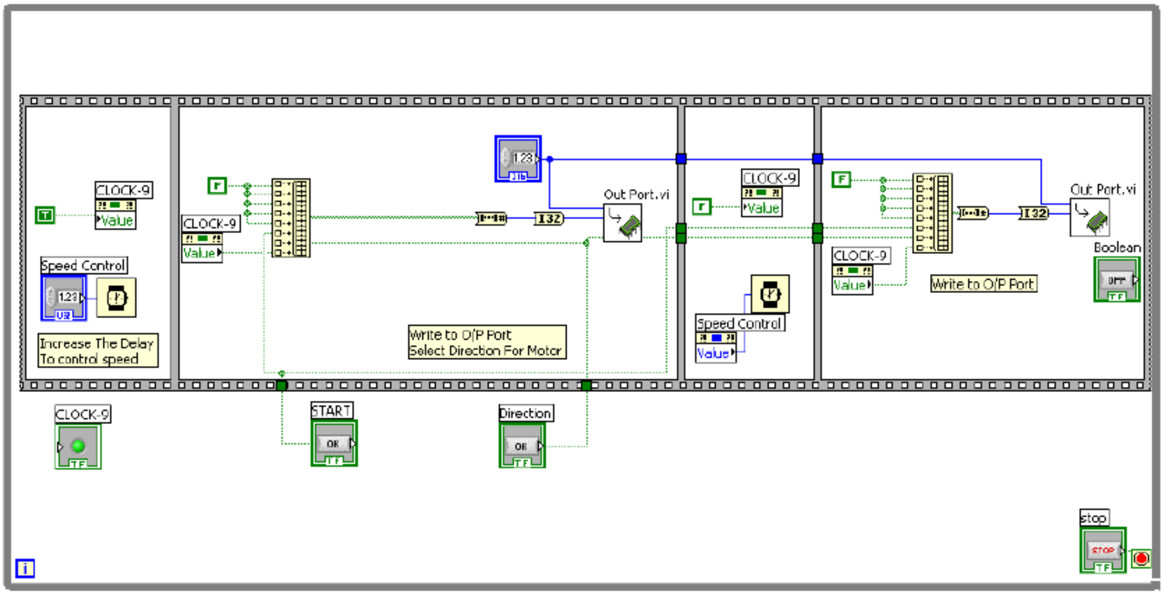
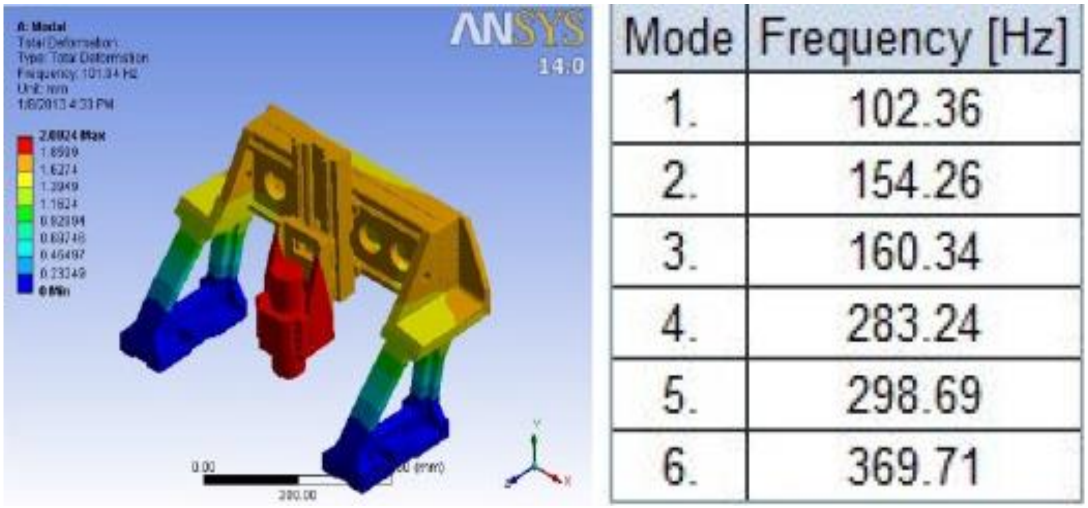


Figure 2. 39 Block diagram of 2-axis stepper motor motion control

In another study, a CNC gantry milling machine with the potenial to produce good surface finish was designed and analyzed. The lowest natural frequency of this machine was 202 Hz coresponding to 12000 rpm at all motion amplitudes with a full range of suitable frequency responses. Meanwhile, the maximum deformation under dead loads for the gantry machine is 0.565 μm, indicating that this machine tool is capable of producing higher product quality. Figure 2.40 shows the spindle at middle positions of y axis. (Ahmed A. D. Serhan, 2014)



Mode	Frequency [Hz]
1.	102.36
2.	154.26
3.	160.34
4.	283.24
5.	298.69
6.	369.71

Figure 2. 40 The spindle at middle positions of y axis

CHAPTER THREE

Selection of Laser Control System

3.1 Introduction:

In this chapter different CNC systems structure, mechanism, motors, electronics, and software are reviewed and discussed. A selection of the best laser control system is introduced in detailed discussion. The best control system means that is the compact, simple mechanism, so easy for the user and capable to be manufactured using conventional technology with a resolution in micron.

3.2 Control system hypothesis:

The control system, CNC system, is selected to process a billet dimension 100 mm as a length and 100 mm as a width with a system resolution in micro-meter.

The CNC system should be stiff enough under high and low speed. To achieve this speed, high and low, a system is selected and designed to be able to attaché y-axis to a pneumatic system for high speed and x-axis to electric motor. For low speed the two axis will attach to two electric motors. The reason for selecting the pneumatic system is the speed of y-axis which is near to 395 mm/s at minimum range which is beyond the capability of the available electric motors

The pneumatic system actuator force is 3kg, so the CNC system or x-y table should be light enough to move by this force. For that Perspex and Teflon is selected as the material for general structure of the x-y table.

3.3 Reviewing control systems:

Control systems are:

3.3.1 Two axes positioning system:

The positioning system is composed of two parts:

a) Mechanical system for positioning on two axes.

b) Control of the two axes positioning system.

a) Mechanical system for positioning on two axes:

The mechanical positioning system is composed of a metallic frame. To which a glass table is fixed, of 52cm/48cm size that has the role to support the paper sheet by means of four clips. The frame is also supporting the positioning system on the ox axis, composed of a step-by-step motor, guiding bars of the cursor, cogged belt that assures the transmission and sustaining frame. To the cursor of the ox axis positioning mechanism the sustaining frame of the oy axis positioning mechanism is fixed. This is composed of the step-by-step motor, two metal guide ways for supporting the cursor. A cogged belt that assures the transmission and a writing instrument (Livinti, 2012).

b) Control of the two axes positioning system:

The components of the control system are:

a) Step-by-step motor with step angle 3.6^{o}
b) Driver for the step-by-step motors.
c) Voltage supply source (0-24) V.D.C. for the step-by-step electric motor
d) IBM PC compatible computer. Equipped with PCI 6251 data acquisition board.
e) Connection coupling of the data acquisition board.

For controlling the step-by-step motors a program has been issued in the LabVIEW programming environment. Figure 3.1 shows the positioning system (Livinti, 2012).

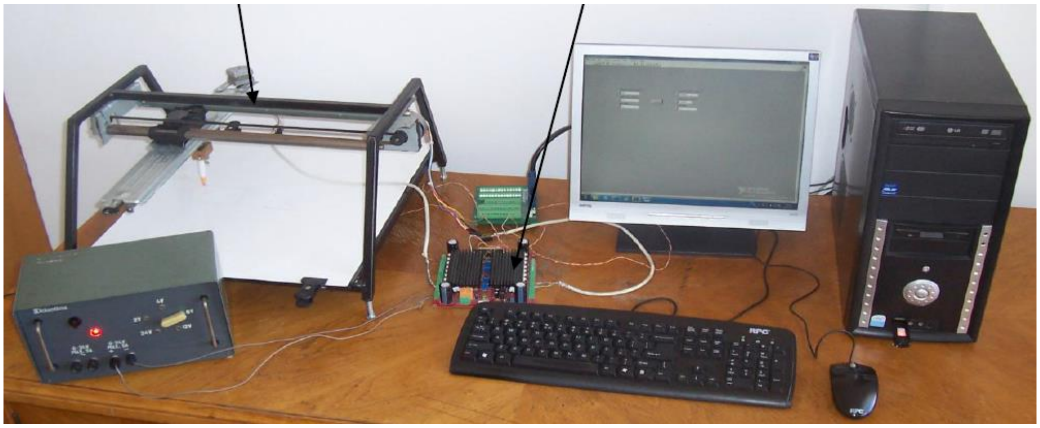


Figure 3. 1 The positioning system

3.3.2 X-Y plotter:

X-Y plotter design is concerned, axis movements are mounted on each other and belt driven mechanism for plotting. Main applications are engraving machine, CNC machine, and graph plotting machine. Stepper motor, timing belt, timing pulley are used for positioning and to provide better accuracy. Main advantage of this plotter can replace the tool based on any application such as engraving machine, laser cutting machine, painting any surface and drawing purposes.

Ultra-low power microcontrollers of MSP430 is used which consumes only 3.5v as input. Figure (3.2) shows block diagram of complete setup

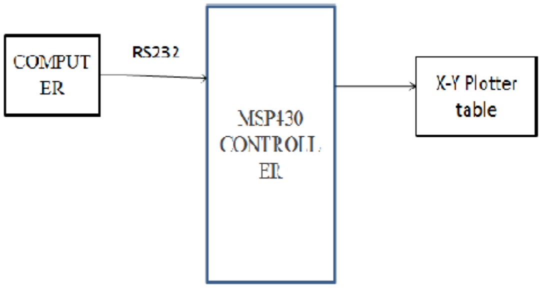


Figure 3. 2 Block diagram of complete setup

Main components of hardware design are stepper motor, guiding shaft, limit switch, aluminum profile, PU belt, pulley, and bearing, connecting wires, nylon block and MSP430 microcontroller (R Dayana, 2014).

a. Stepper motor:

Main two models are unipolar and bipolar stepper motor. 6-wire unipolar hybrid synchronous motor of 1.8 degree step angle is used for better positioning and accuracy.

b. Guiding shaft:

For the movement of solid block structure to move along its path without any shake, guide rod is used. Based on load, EN8 material is used for guide rod.

c. Poly urethane belt:

There are several types of belt made of different material. Belt is 1100mm circumference, 5mm pitch (T5), and width of 9mm is used.

d. Bearing:

Linear and ball bearing are used. Linear bearing is used for linear movement in guiding shaft and ball bearing is used for rotational movement in free end pulley support. Based on the outer diameter of guiding shaft, both linear and ball bearing are chosen.

e. Microcontroller:

From figure below represents MSP430G2 launch pad is used with controller family number MSP430G2553 of 20 pin in it. It is ultra-low power microcontroller of 3.5v with inbuilt UART, UCSI in the launch pad. Figure 3.3 shows hardware setup.

f. MATLAB:

Input signals are generated in MATLAB and given to microcontroller through UART.

g. IAR Embedded workbench:

Programs are written in C language. (R Dayana, 2014).

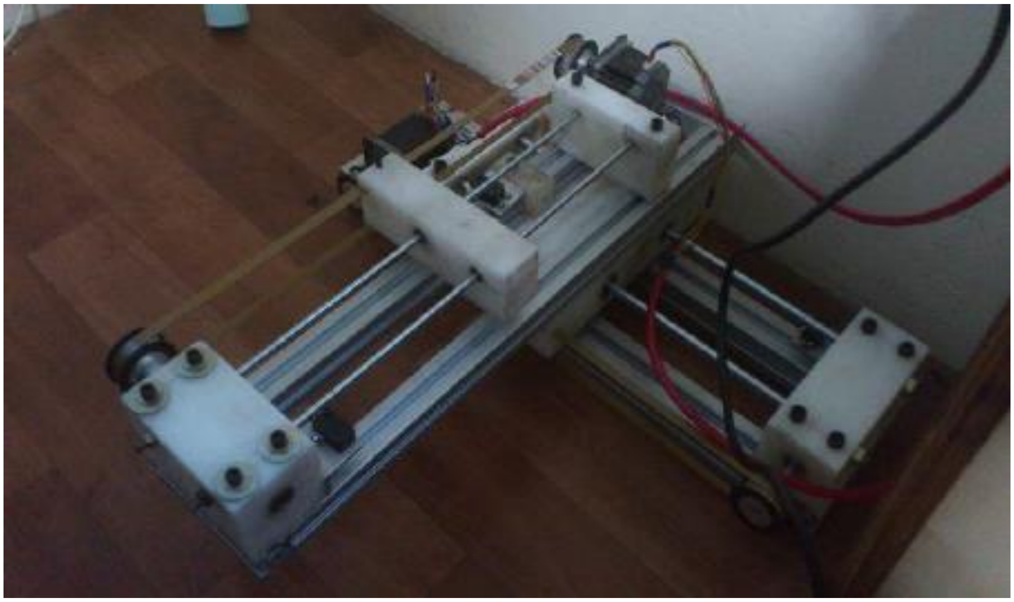


Figure 3. 3 Complete hardware setup

3.3.3 Three-Axis CNC Router:

This system can be divided into three modules. As shown in figure 5 mechanical system gets necessary control signals from electronics system which ultimately results in desired actuation of motors. Electronics system gets command or a set of commands from software system and generates controls for mechanical system. Figure 3.4 shows block diagram of overall process (Dr. B. Jayachandraiah, 2014).

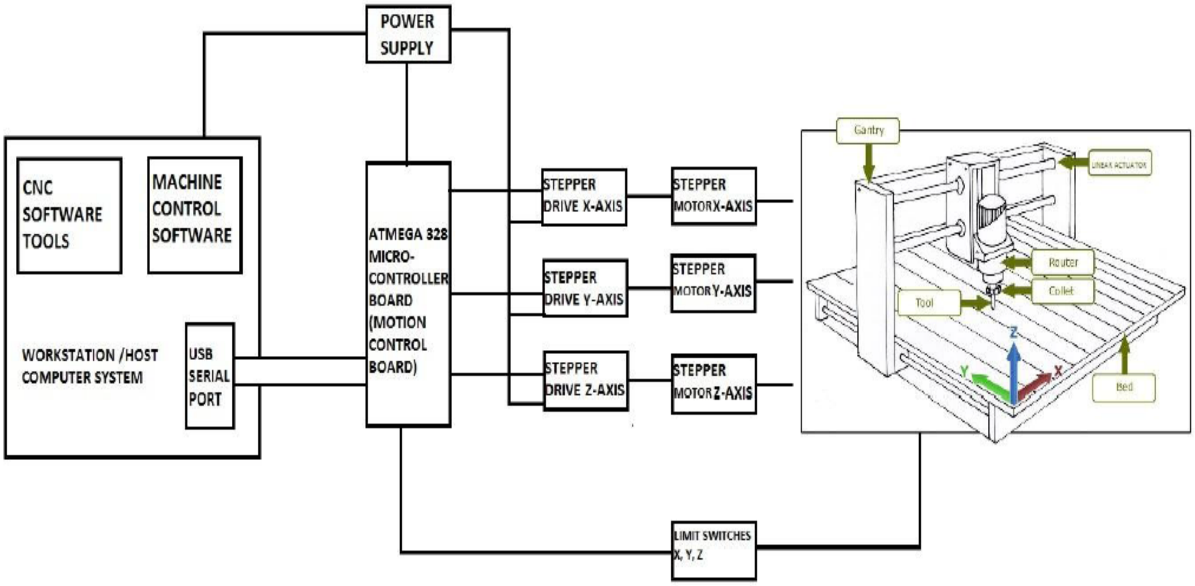


Figure 3. 4 Block diagram of overall process

a) Mechanical system:

The mechanical system which is assembled in such a way that the 3-axis movement is achieved by using the linear rails assembled with linear bearings. Stepper motors are mounted to the each axis which is source of motion acted according to the control signal generated from the electronics circuit. Each stepper motor is coupled through the shaft couplers to each of the Lead/Ball screw of each axis which is responsible for converting the rotational motion of the stepper motor to linear motion. The linear motion of each axis is carried away smoothly by the linear rail assembly connected to the each axis which is capable of load carriers and allow linear motion in each axis. The controlled motion in each axis is achieved directly by controlling the rotation of the stepper motor. The speed of the motion in each axis can also be controlled by direct control of the speed of the stepper motor by giving required control signals. Thus the tool path of the spindle fixed to the end effector is controlled in each axis for smooth carving or cutting action of work piece.

b) Electronics system:

Electronics system is responsible for generating control signal to the stepper motors which guides the motion of tool path in each direction of axis. Electronics system is comprises of:

1- Power supply:

Power supply is heart of the CNC system which converts the AC voltage to DC voltage and supplies required voltages to the corresponding devices. Microcontroller board receives 12v supply whereas the stepper motor board receives 48v.

2- Microcontroller board:

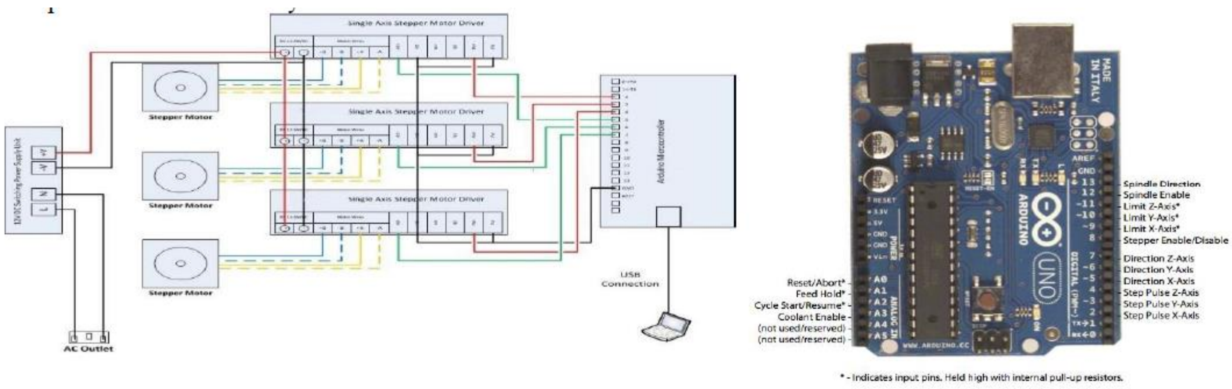
Atmega 328p Arduino based microcontroller development board is chosen here to control the motion of the system. It acts as the brain of the CNC system which receives the commands from the software system from computer connected through the USB serial port. Arduino development board is flashed with the G-code interpreter code which was written in the C language. Which is responsible to generate the control signal for corresponding command signal from the computer system to the stepper motors which directly controls the motion of the tool path. The commands from computer or software system is received and convert them to the actual electronic signals to the stepper motor driver board.

3- Stepper motor drive board:

RMCS-1102 is micro-stepping drive designed for smooth and quiet operation is chosen to drive the NEMA 23 stepper motor. Stepper motor drive board receives the control signal form the microcontroller board to the terminals Pulse and DIR which generates the corresponding digital pulse signals for 4 lead stepper motor to control the rotation of the motor.

4- Electronics circuit wiring:

The wiring of the various components of electronics system is represented in the Fig. shown below. The microcontroller board is connected to the computer system through the USB serial port. The stepper motor drive board terminals PULSE and DIR of each board is connected to the microcontroller terminals from 2 to 7 pins respectively. Terminals A+, A-, B+, and B- of stepper motor drive board are connected to the 4 lead stepper motor directly. Power supply is provided for all the components of electronics system. Figure 3.5 shows electronic circuit wiring.



* - Indicates input pins. Held high with internal pull-up resistors.

Figure 3. 5 Electronics circuit wiring and microcontroller pin configuration

To avoid the axis motors going out of safe operating range, six limit switches have been installed two for each axis. An emergency stop button manual operation has also been used for the machine.

5- CNC control software:

G-code sender is used to send the G-code files to an integrated hardware interpreter (ATmega 328). G-code sender will take a G-code program in file and send it line-by-line to the Atmega 328 microcontroller. The G-code will send over the serial ports through USB communication between the computer and microcontroller. Grbl controller is software that is designed to send G-code to CNC machine is, such as 3D milling machines. It isn't super smart, it just needs to give the user a nice way to get commands down to whatever controller they are using.

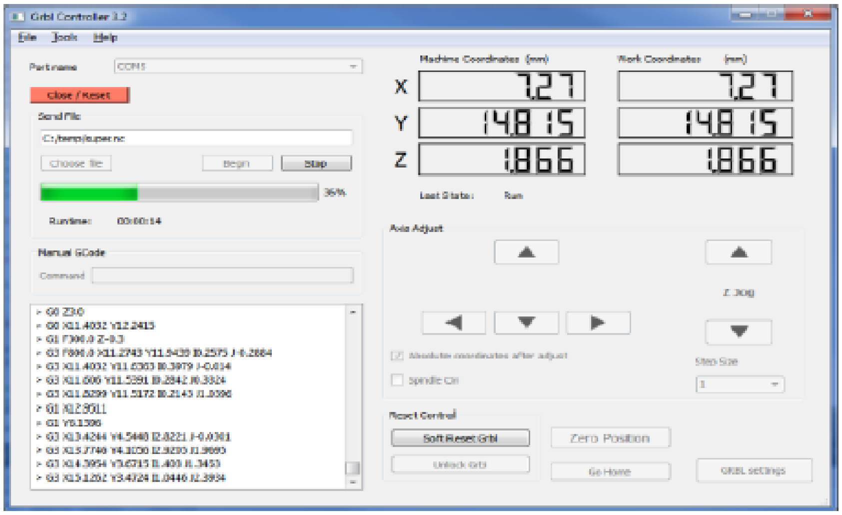


Figure 3. 6 CNC control software window

6- G-code firmware for microcontroller:

G-code firmware is the brain of the machine which is responsible for tool path control G-code firmware is a program code written in optimized C language which interprets compile the G-codes. G-code firmware reads each line of the G-code file received and generates the actual electronic signals to the motors and thus motion is controlled over the three axis (Dr. B. Jayachandraiah, 2014).

3.3.4 Patriot CNC Router System:

The Patriot CNC Router, shown in figure 3.7, is designed for basic prototyping applications such as engraving, dental impressions, jewelry, orthopedic models and many other applications. It is constructed with precision ball screws on all three axes and utilizes a closed-loop servo control system.

The Patriot has a working travel of 14.7x10.8x6.8 inch and has a physical footprint of 28x31x42.5 inch. It has a repeatability of fourteen-thousandths of an inch and a position accuracy of two thousandths of an inch.

This CNC accept any file size and uses a standard Windows application interface that utilizes industry standard G&M-code (James Williams, 2009).

Figure 3. 7 Patriot CNC Router

3.3.5 Desktop CNC Router with Servo Control:

This CNC router system, shown in figure 3.8, is a compacted desktop unit that provides a full 12 x 24 x 4 inches of travel. Its uses include woodworking, PCB trace routing, drilling, engraving, 3D surface milling cutouts and many other applications. It uses a servo control system that provides speeds up to 350 inches per minute. Desk CNC control hardware and software are included. It uses a standard RS-232 serial link.The mechanical drive system utilizes precision Thompson rods with linear ball bearings on the Z axis. The X and Y axes use V-groove bearing wheels and steel track. The framing is black anodized aluminum. It uses a moving table design approach, so that the X axis gantry remains fixed (James Williams, 2009).

Figure 3. 8 12 x 24 Desktop CNC Router

3.3.6 CNC Shark Routing System:

Figure 3.9 shows the most portable CNC router system available from Next Wave Automation. As with most CNC's, it can be used for woodworking, PCB, engraving, drilling and 3D milling applications among other things.

Figure 3. 9 CNC Shark

This particular unit utilizes an all plastic (HDPE) frame which is aluminum reinforced where need for additional rigidity. The plastic frame makes the machine like weight and induces a cheaper construction cost. The table top is constructed of wood. The machine uses precision linear bearing guides on all axes. It has a travel of 13 x 24 x 4.25 inches.

The CNC Shark uses a USB interface that includes memory storage on the controller. It uses stepper motor drive technology and uses a 24V motor supply system. Mach3 software is provided for machine control. The basic software provides on G&M-code file support (James Williams, 2009).

3.3.7 CNC laser cutting and engraving machine:

The machine is designed to be very compact with outer dimensions being 950mmx700mmx320mm weighing 30kgs and works on a 40Watt CO_2 sealed water cooled laser tube and having a work space of 28"x18". The gantry is made of modular aluminum 1010 extrusions with custom designed pulley bearing shaft assemblies and T2.5 PU synchronized belt drive. Hiwin HG-15 linear bearing guideways are used for linear motion in x and y directions.

The Gantry is driven by 18Kgcm stepper motor (SY57STH76-2804A) for y axis control and 12.6 Kgcm motor (SY57STH56-2804A) for x axis control using 2 lead shine sinusoidal current control technology drivers running on 1/32 micro stepping for smooth and accurate movement.

- Electronics, user interface and control:

The electronics consists of a separate power supplies for laser, motors and a central board which breaks input-output signals for the motion and laser control, IR motion limit switches, relay controlled water cooling, air assist system and exhaust, other safety features and runs a user friendly interface with a control panel for switches and LCD display on the machine. Art soft Mach3 computer numerical control software is used to control the whole machine including the laser and drive motion running with transmission via parallel port (Deepak, 2013).

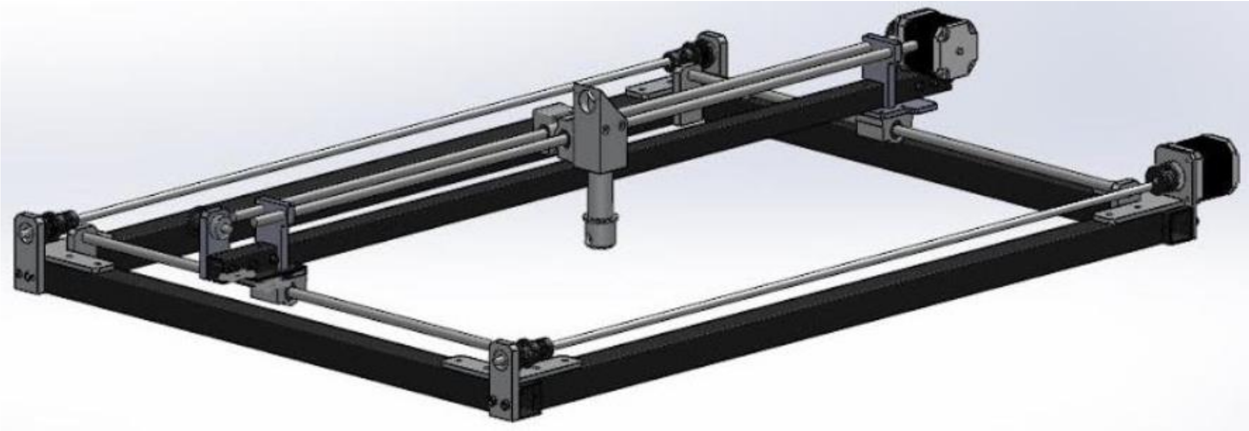


Figure 3. 10 CNC gantry

3.3.8 CNC system with open software tools:

A system is proposed with open components. A desktop PC is used to run all the required software. The embedded control unit is interfaced to the PC using RS232 serial communication. The control unit is connected to the motors using drivers. (Aji Joy, 2014).

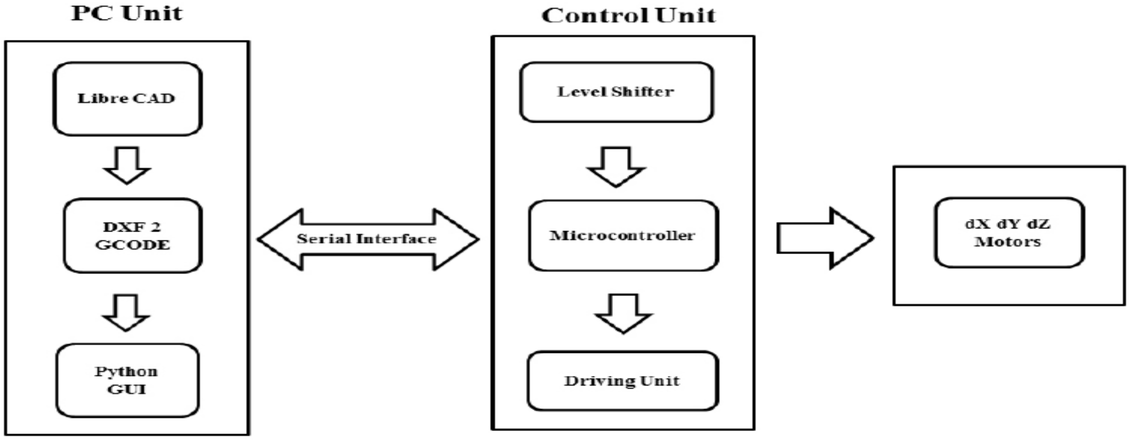


Figure 3. 11 Block diagram of the proposed system

A. Desktop PC unit:

a. Ubuntu Linux:

Ubuntu is a computer operating system based on the Debbian Linux distribution.

b. Libre CAD:

is a free computer aided design application for 2D design.

c. DXF2G-code:

It is software to convert AutoCAD drawing image files to G-code.

d. G-codes and M-codes.

e. PYTHON:

A programming language with powerful typing and object oriented features.

f. ERIC PYTHON IDE:

Eric is a full featured python and Ruby editor and IDE, written in pathon.

g. pySerial:

pyserial is a python serial port extension for Linux.

B. Control unit:

a. Level shifter:

Level translator chip used is MAX232.

b. Microcontroller:

Microcontroller used is PIC 16F877A. The 16F877A is programmed using MPLAB high level language.

c. Motor drive:

ULN 2803 is octal high voltage.

c. circuit diagram: (Aji Joy , 2014)

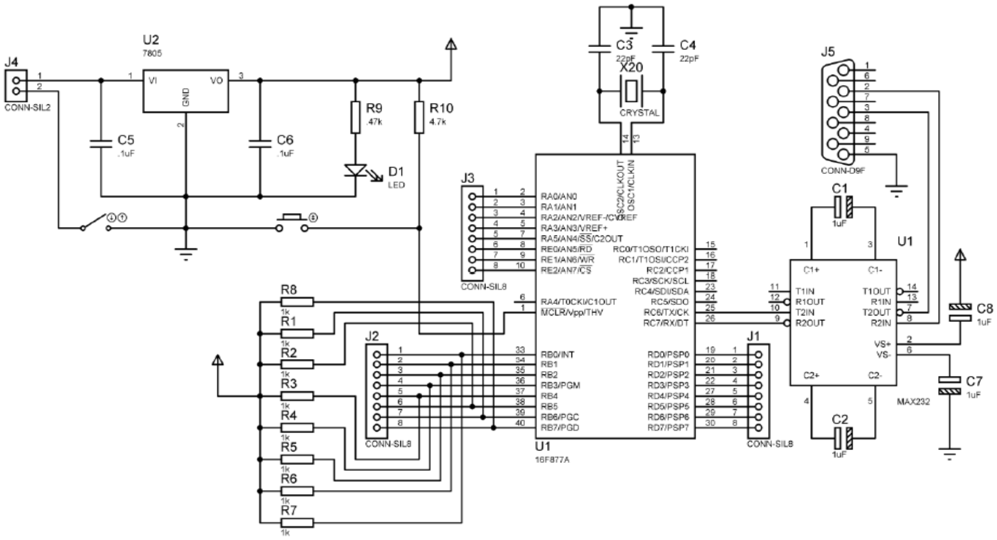


Figure 3. 12 Microcontroller unit

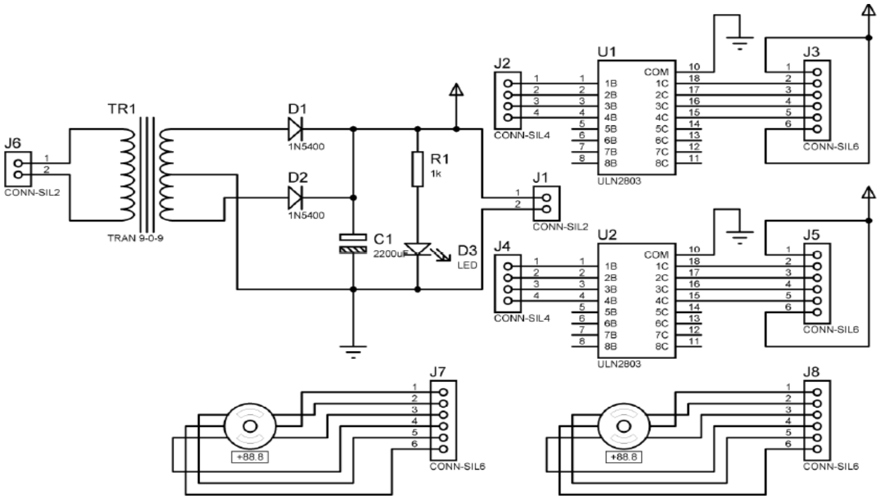
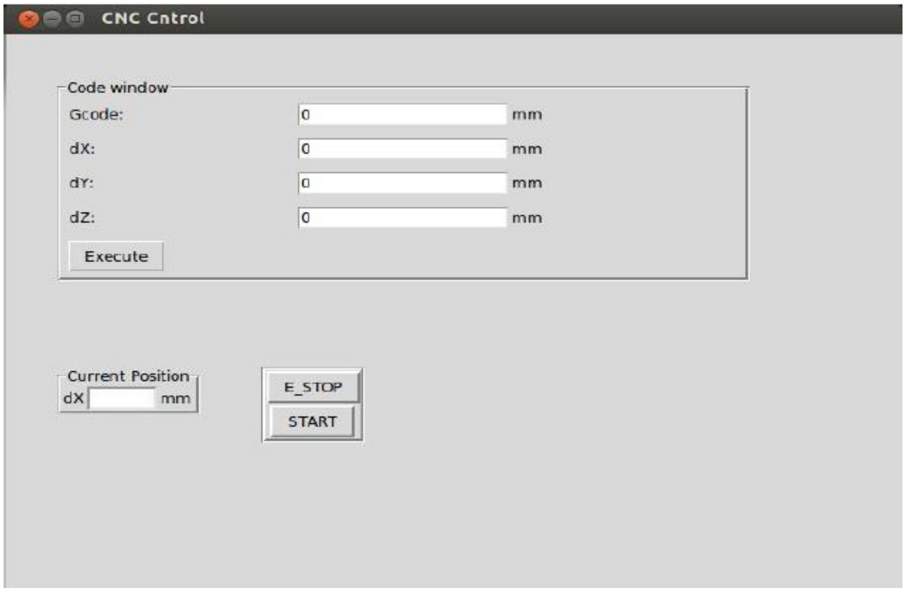


Figure 3. 13 Drive unit



Gcode: 0 mm

dX: 0 mm

dY: 0 mm

dZ: 0 mm

dX mm

Figure 3. 14 sample GUI developed using Python

3.4 Discussion of subsystem:

3.4.1 Rail system:

In the reviewed controlled systems there are different types of railing mechanisms:

Steel shaft railing seen in figure 3.15a also railing system with v-groove bearing wheels and steel track seen in figure 3.15b. The shaft and support system in this particular system can come in a ceramic material which provides enhanced properties of the system. The enhanced properties include a reduction of vibration while also reducing deflection of the shaft during loading cases to help increase the life of the shaft.

(a) (b)

Figure 3. 15 Steel shaft railing system

Guided rod with sliding bearing, which uses a shaft and support system to support loading applications along the shaft, along with forces from linear motion this sort of railing can support in some way to handle the loads applied to it without much deflection and simply allow unrestricted movement along their lengths or a guided rod with a linear bearing as in fig. (3.16), laser bot, which are rigid enough to be used at horizontal and vertical position.

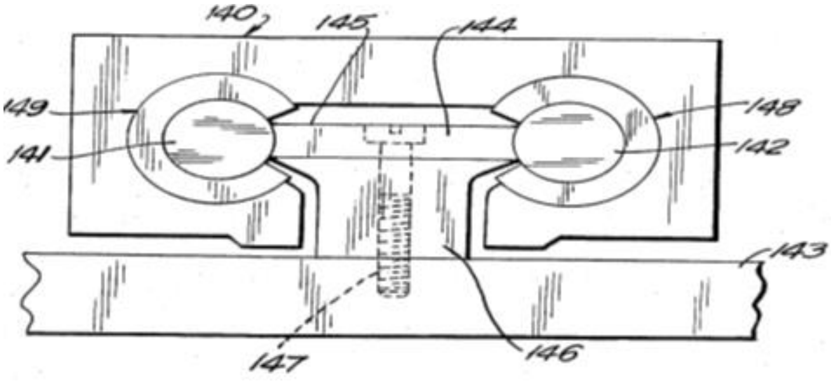


Figure 3. 16 Linear bearing

The V-notch rail system uses a notch in the rail and V-grooved wheel riding on the railing surface to carry the load and support linear motion, involves a Versa-Mount guide block and rail. This system is capable of higher loading capacities with stability in handling off-balanced loads, along with being oriented in any position and still maintaining approximately the same load capacity due to its rigidity.

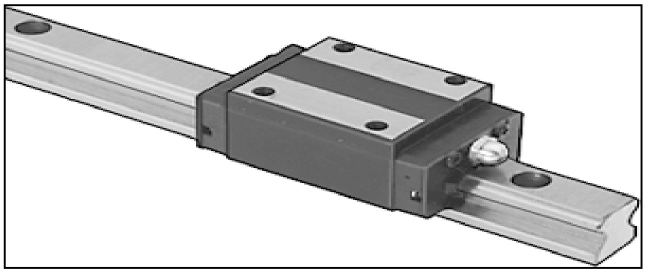


Figure 3. 17 V-notch rail system

3.4.1.1 Selection of x-axis rail:

This axis is always selected to run at low speed with a travel length not more than 100mm; a cording to billet dimension it should have minimum weight, no slip stick. The best selection is a two rods as guided shaft with three rectangular Perspex plate. Two plates at the end of the guided shaft work as shaft support and have a groove in the center for deep groove ball bearing work as two supports for the power screw. The plate between them hold the x-axis table. The power screw nut is fixed at the central plate. Fig. (3.18) below shows the x-axis rail.

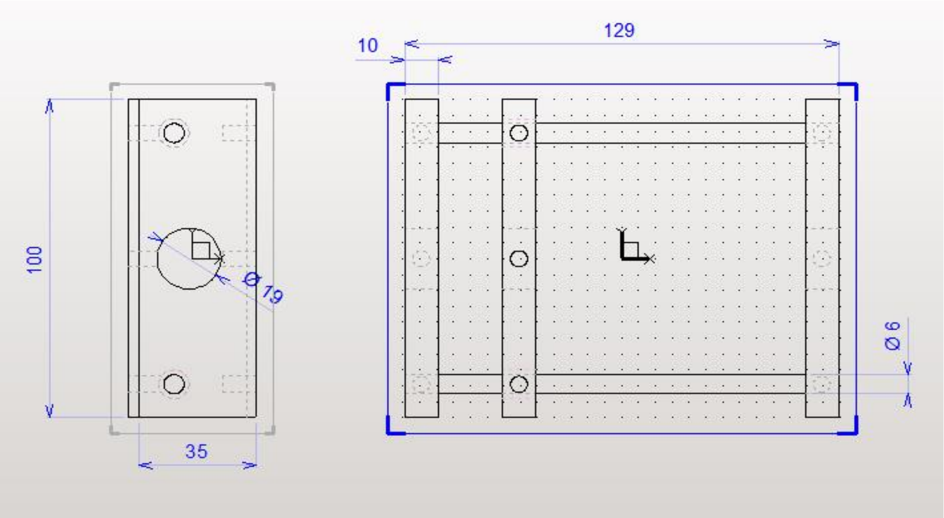


Figure 3. 18 The x-axis rail

3.4.1.2 Selection of y-axis rail:

This axis is selected to accept the high and low speed with a minimum inertia without slip stick and antifriction is necessary to this axis so four roller bearing is a best solution. The four bearing is fixed at two rectangular Perspex plate with one plate at the shorter side at the top of them, which is holding the x-axis rail. The power screw or the pneumatic actuator is connected to the y-axis rail through rectangular plate fixed at top plate at the longer side with two slots using two screw. Figure 3.19 show the y-axis rail.

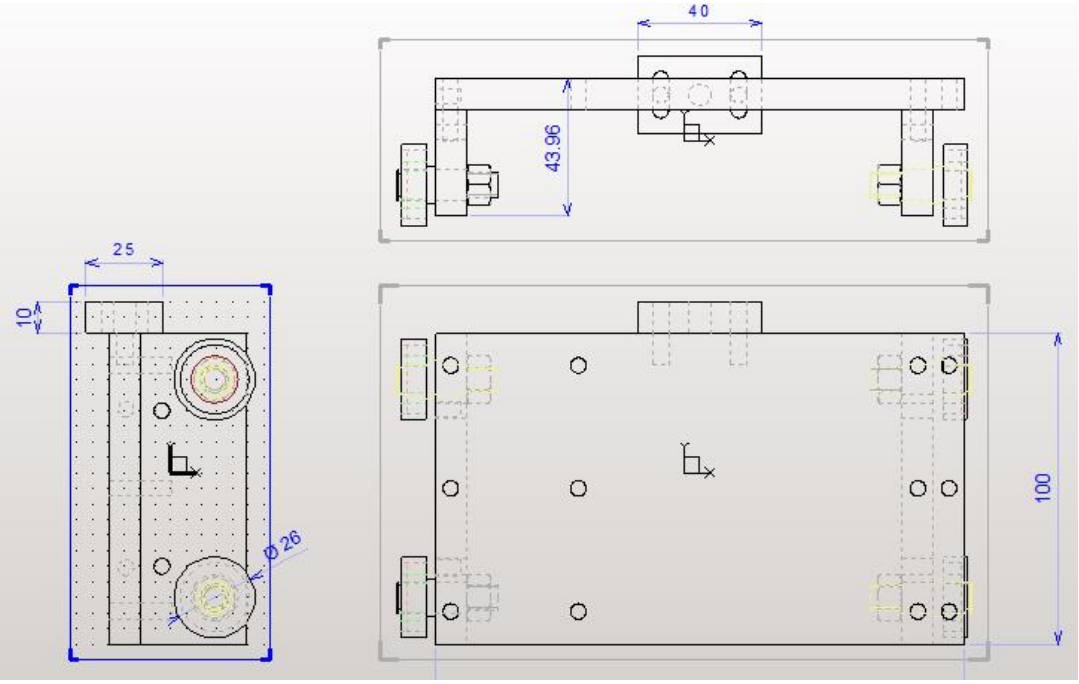


Figure 3. 19 The y-axis rail

3.4.2 Mechanical drive subsystem:

The purpose of the drive mechanics is to transfer the torque provided by the electric drive motors into linear motion to move the x and y table. The mechanical drive used in different subsystem are acme thread trapezoid and ball screw as the power drive. The ball screw need less power than the two others and have less coefficient of friction.

3.4.2.1 Selection of the Mechanical drive system:

Always the best selection is the ball screw. But at this project the x and y table is small and have a light weight. The rotational speed and linear speed is low. So the required torque is small. For that a fine fastener thread, M8x1, is the best selection. To avoid backlash problem flexible Teflon nut was used. Figure 3.20 below shows the mechanical drive system.

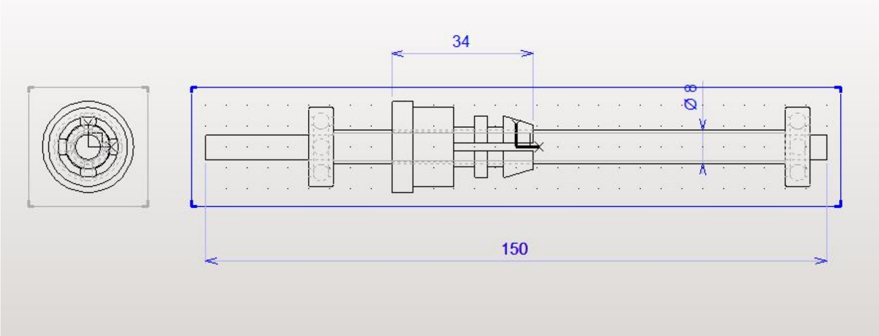


Figure 3. 20 Mechanical drive system

3.4.3 Communication:

The different system of communication, USB, parallel and serial system, are used to communicate the PC to MCU. Here is how USB stacks up against other protocols available for other host adapters:

Table 3. 1 USB, Serial and Parallel protocol

	USB 3.1 Gen 2	**USB 3.1 Gen 1 (USB 3.0)**	**USB 2.0**	**USB 1.1**	**Serial**	**Parallel**
Industry Standard	Yes	Yes	Yes	Yes	Yes	No
Bandwidth	10 Gbps	5 Gbps	480 Mbps	12 Mbps	115 Kbps	115 KBps EPP/ECP - 3 MBps
Number of Devices	127 devices on a single USB bus	127 devices on a single USB bus	127 devices on a single USB bus	127 devices on a single USB bus	Limited to the number of ports available on the computer.	Limited to the number of ports available on the computer.
Bus Power	Yes, can provide up to 900 mA at 5V (Also USB Power Delivery)	Yes, can provide up to 900 mA at 5V (Also USB Power Delivery)	Yes, can provide up to 500 mA at 5V	Yes, can provide up to 500 mA at 5V	No	No

Cable Length Limit	Cable can be of any length as long as electrical spec is met. Practical max length is 1m.	Cable can be of any length as long as electrical spec is met. Practical max length is 3m.	5 m / 16 ft	5 m / 16 ft	3 m / 10 ft	1.8 m / 6 ft
Plug'n'Play	Yes	Yes	Yes	Yes	No	No
Hot Swapable	Yes	Yes	Yes	Yes	No	No

The serial port does not suffer the same problems of the parallel port. The behavior of the serial port has been standardized across computers so there are no surprises there. The real problems are: bandwidth and limited ports. The serial port is the slowest of the group.

The Parallel port can be fast enough for most applications, but it suffers from many problems. The most significant issue is that the port is non-standard. Often times, users of the parallel port will run into OS issues or BIOS issues. Most manufacturers have different implementations of the parallel port. On most computers there is usually only one parallel port available which can cause many headaches if that port needs to be shared.

3.4.3.1 Selection of Communication:

The USB system is a best selection duo to comparison done in chapter three. But Serial Communication Protocol RS-232, DB-9, is quite enough when using Microcontroller that have a number of pins which can be used in a different of applications. Serial system in a full duplex is used and attached to USB to serial converter to be able to use laptop or desktop computer. Figure 3.21 show the communication system used.

Figure 3. 21 USB to serial

3.4.4 The Drive system:

Stepper and servo motor was the driving system of the different CNC system. Some performance differences between Stepper and Servos are the result of their respective motor design. Stepper motors have many more poles than servo motors. One rotation of a stepper motor requires many more current exchanges through the windings than a servo motor. The stepper motor's design results in torque degradation at higher speeds when compared to a servo. Using a higher driving bus voltage reduces this effect by mitigating the electrical time constant of the windings. Conversely, a high pole count has a beneficial effect at lower speeds giving the stepper motor a torque advantage over the same size servo motor.

Another difference is the way each motor type is controlled. Traditional steppers operate in the open loop constant current mode. This is a cost savings, since no encoder is necessary for most positioning applications. However, stepper systems operating in a constant current mode creates a significant amount of heat in both the motor and drive, which is a consideration for some applications. Servo control solves this by only supplying the motor current required to move or hold the load. It can also provide a peak torque that is several times higher than the maximum continuous motor torque for acceleration. However, a stepper motor can also be controlled in this full servo closed loop mode with the addition of an encoder.

Steppers are simpler to commission and maintain than servos. They are less expensive, especially in small motor applications. They don't lose steps or require encoders if operated within their design limits. Steppers are stable at rest and hold their position without any fluctuation, especially with dynamic loads.

Servos are excellent in applications requiring speeds greater than 2,000 RPM and for high torque at high speeds or requiring high dynamic response. Steppers are excellent at speeds less than 2,000 RPM and for low to medium acceleration rates and for high holding torque.

3.4.4.1 Selection of the drive system:

The stepper motor is the best selection according to characteristics that reviewed before. In addition the stepper motor is very suitable at CNC system which doesn’t have tool contact with billet. Two bipolar stepper motor, four and eight wire, was selected with step angle 7.5^o and holding torque 0.13 Nm. Oldham flexible coupling is selected as a joint between stepper motor and the power screw, to correct the assembly miss alinement and manufacturing errors.

Motor sizing:

Motor sizing equation was calculated at excel program as shown in table below.

Table 3. 2 Motor sizing

Conditions & consitants		
Total mass (tables & billet)	**3**	**kg**
Desired resolution (in micron range)	**0.02**	**mm**
max. feed speed	**5**	**mm/s**

friction coefficient of sliding surface (lubricant)	**0.15**	
friction coefficient of screw	**0.04**	
screw total length	**150**	**mm**
screw efficiency	**0.3**	
steel density	**7850**	**kg/m3**
factor of safty	**2**	
Feed	**100**	**mm**
From screw tables		
screw pitch	**1**	**mm**
screw diameter	**8**	**mm**
Motor sizing calculations		
positioning period	**20**	**s**
required resolution= 360*desired resolution/ scew pith	**7.2**	**deg.**
step angles 0.72,0.9,1.8…….etc	**7.5**	**deg**
gea reduction i	**1**	
operating pulses=feed per uint*360/(screw pitch*step angle)	**4800**	**pulses**
acceleration period=0.25*positioning period	**5**	**s**
start pulse speed	**0**	**Hz**
operating pulse speed V2=	**320**	**Hz**
number of operating pulses - start pulse speed*acceleration period		
positioning period - acceleration period		
operating speed=operating pulse speed*step angle*60/360	**400**	**rpm**
motor speed=operating speed/i	**400**	**rpm**
load torque TL =mgμsL[1/η+μo/3]/2πi **TL=**	**0.002352525**	**N.m**
screw moment of inetia j=πρLD4/32	**4.73261E-07**	**kgm2**
Table moment of inertia=m(pitch/2π)^2	**7.6068E-08**	**kgm2**

load inertia= screw inertia+table inertia	**5.49329E-07**	**kgm2**
acceleration torque Ta=		
(Jo+J)*πϴ(V2-V1)/(180*t1)		
	4.59971E-06	
	8.0384	
Ta=	**B49*Jo+B48**	**N.m**
	0.00471425	
	16.0768	
Required torque Tm = (TL+Ta)Sf **Tm=**	**B53*Jo+B52**	
Jo	**0.0000035**	**kg.m2**
Tm	**48.62914558**	**g.cm**
motor pulse per second	**320**	**Hz**
Motor step angle	**7.5**	**deg**
motor holding torque	**48.629146**	**g.cm**
motor type	**PM**	

3.4.5 The software:

Labview and c++ language were used to communicate the user with the machine. In addition, other software packages were used in the reviewed systems:

1- Mach 3:

Mach 3 is a CNC software system that works with a full PC 6-axis CNC controller. Mach 3 can import DXF, BMP, JPG, HPGL files to create an image that can be machined with the CNC. This program which was created by Art Soft was designed for small businesses and hobbyist. It has high resolutions for the users who enjoy GUI interfaces. Mach 3 uses three external software packages:

Lazy Cam, Wizards, VB scribe. Lazy Cam allows the user to import different files types to the CNC controller and transfers them into G-code files. Wizards are a mini program that allows the user to write their own G-code easily. It has many capabilities such as gear cutting, digitizing, holes, slots, text engraving, and more. It also gives premade designs from the company so no need to create a standard G-code file. Mach 3 requires a desktop PC due to the power saving control implemented on the laptop.

2- Enhanced Machine Controller (EMC):

EMC is open source software for Linux operating systems. It is designed from hobbyist and even industrial type settings but requires lots of configuring. This program was designed for users who understand programming and configuration processes to allow them to make the EMC the way the user wants it. This program does not have a high resolution GUI interface.

3- BOBCAD CNC:

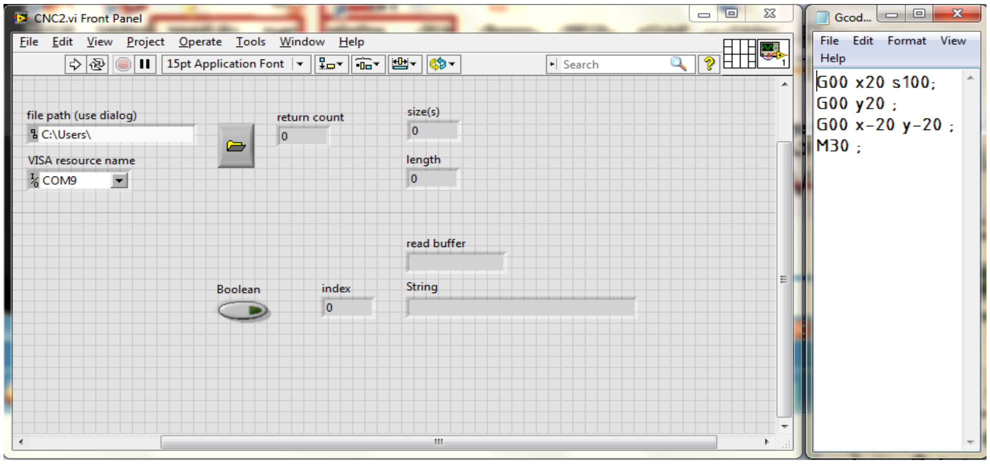
BOBCAD CNC is a powerful CNC software that has a lot of capabilities. It has the ability to do milling, lathing, art, wire, nesting, and CAD drawings. The2D and 3D interface that goes with this program is key for artist and hobbyist who want to create something precise. BOBCAD is very user friendly program that doesn't need any type of configuration. BOBCAD's capabilities include text and geometry, surfaces and solids from text, geometry and solid editing, geometry verification, part dimensioning and spline construction and more. This program also allows to insert directly other file formats to be changed to G-Code.

4- Desk CNC:

Desk CNC is simple and constructive software to use. It has the abilities to do contour, pockets, drills and more. It has the ability to do 3D images in a less high resolution GUI atmosphere. This program also has the capabilities to upload different types of file formats that can be converted to G-Code and ran with the CNC. Desk CNC also has the ability to upload Gerber files to construct circuit boards.

3.4.5.1 Selection of the software:

LabVIEW is selected as a GUI control system software instead of using available packages Mach3, EMC, BOBCAD CNC, desk CNC. The reason beyond selecting this software, LabVIEW, to write the control program are the simplicity of using LabVIEW and it can be modified easily to accept the improvement in the electronic system. Figures 3.22 and 3.23 show the front panel, user window, and block diagram which display LabVIEW program.



file path (use dialog): C:\Users\

VISA resource name: COM9

return count: 0

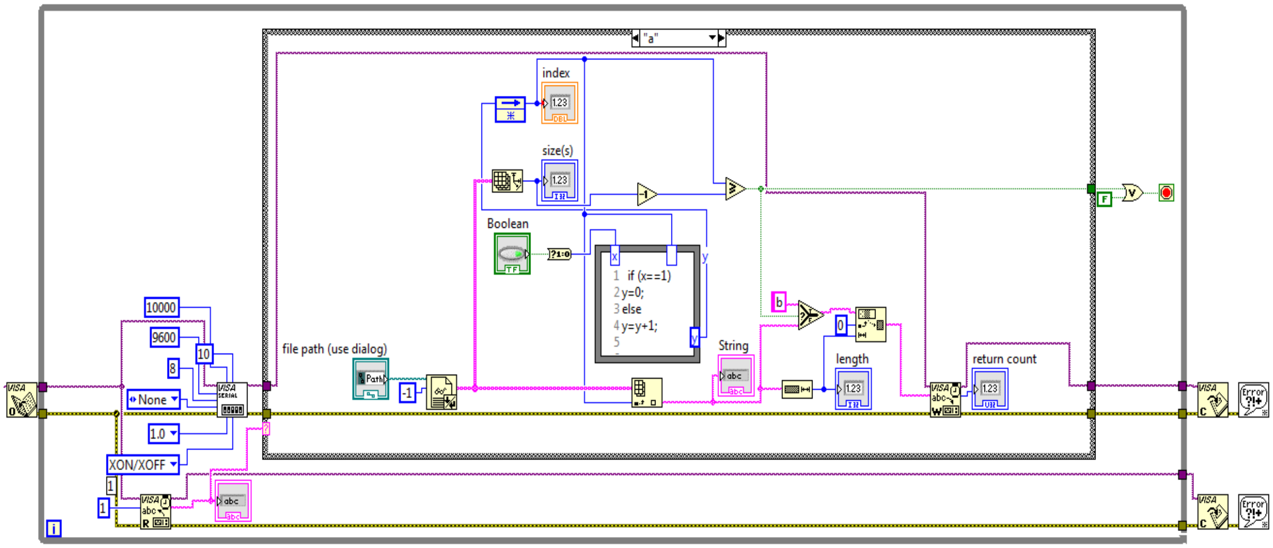
size(s): 0

length: 0

index: 0

```
G00 x20 s100;
G00 y20 ;
G00 x-20 y-20 ;
M30 ;
```

Figure 3. 22 The user window



```
if (x==1)
y=0;
else
y=y+1;
```

Figure 3. 23 Block diagram (programmer window)

The user write G-code program in a notepad file, text file, using G00 as a code to move the x-axis table and y-axis table. Table speed can be controlled using s as speed code. The end of G-code program is the code M30. Sample program is shown in the figure 3.22 above.

3.4.6 Electronic system:

Both Microcontroller and Arduino based microcontroller are used as MCU of the control system. Arduino is a board on which all the things are built in for example the analog input and output. For ordinary micro controller it have to connect a ADC(Analog to digital converter)converter with the micro controller to convert digital signal to analog and analog to digital. The stepper motor is very easy to run on Arduino because it has 5v supply pin on Arduino board as well as ground where as using a simple micro controller it have to connect a motor driver IC. Which supply enough power to run the motor. Thus more power is needed to run the controller as well as the driver IC. More over using ordinary micro controller first hex file have to be created for the code and then burn it in the micro controller using a burner which is little harder than Arduino, because on Arduino it is just connect the board with the PC or laptop using USB connector and directly burn the code on the Arduino board.one more advantage of Arduino that its programming software is open. Arduino provide to code the program using c/c++ language .

3.4.6.1 Selection of the electronic system:

Microcontrollers can do much the same as (or quite a bit more than) the Arduino can. Also it is easy to replace or adding ICs for improving the system. So the best electronic system is the Microcontroller.

The components of the electronic system selected at this research are microcontroller 16f877a, max232, driver L293D. Figure bellow show the circuit diagram in proteus.

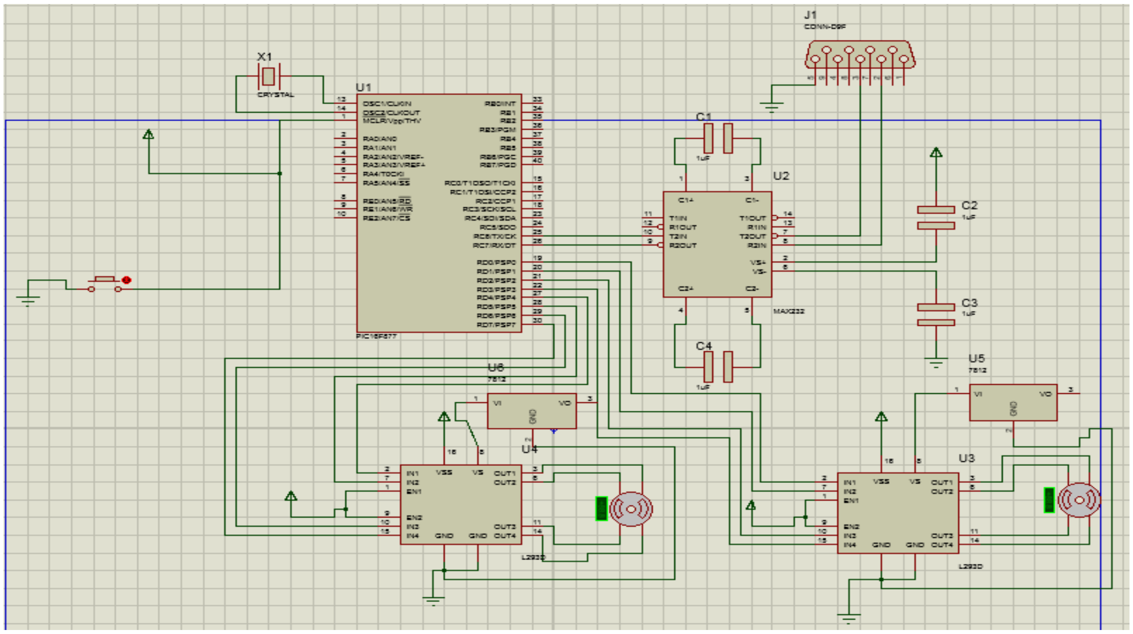


Figure 3. 24 The control system diagram

The microcontroller was programed in more than 120 rows using Mikroc. Sample of the program is displayed below.

```
while (1) {                    // Endless loop
UART1_write_text("a")  ;
    while(!UART1_Data_Ready());       // wait data for received,
```

```
 UART1_Read_Text(i,";",255);    // read the received data,
if(i[0]=='G' && i[1]=='0' && i[2]=='0' ) {
x_count=0;y_count=0;s_count=0;z_count=0;Lx=0;Ly=0;Lz=2;
j=0;rox=0;roy=0;jx=0;jy=0;Lt=0;
x[0]=0;x[1]=0;x[2]=0;x[3]=0;y[0]=0;y[1]=0;y[2]=0;y[3]=0;y[4]=0;y[5]=0;z[0]=2;z[1]=2;
for(n=4;n<55;n++){
if(i[n]=='x'){for(k=n+1;k<15;k++){if(i[k]!=' ' || i[k]!=';'){x[x_count]=i[k];x_count++;}else break;}}
if(i[n]=='y'){for(c=n+1;c<25;c++){if(i[c]!=' ' || i[c]!=';'){y[y_count]=i[c];y_count++;}else break;}}
if(i[n]=='z'){for(e=n+1;e<n+2;e++){z[z_count]=i[e];z_count++;}}
if(i[n]=='s'){for(h=n+1;h<n+3;h++){s[s_count]=i[h];s_count++;}}
}
```

Figure (3.25) below shows the selected control system, CNC system.

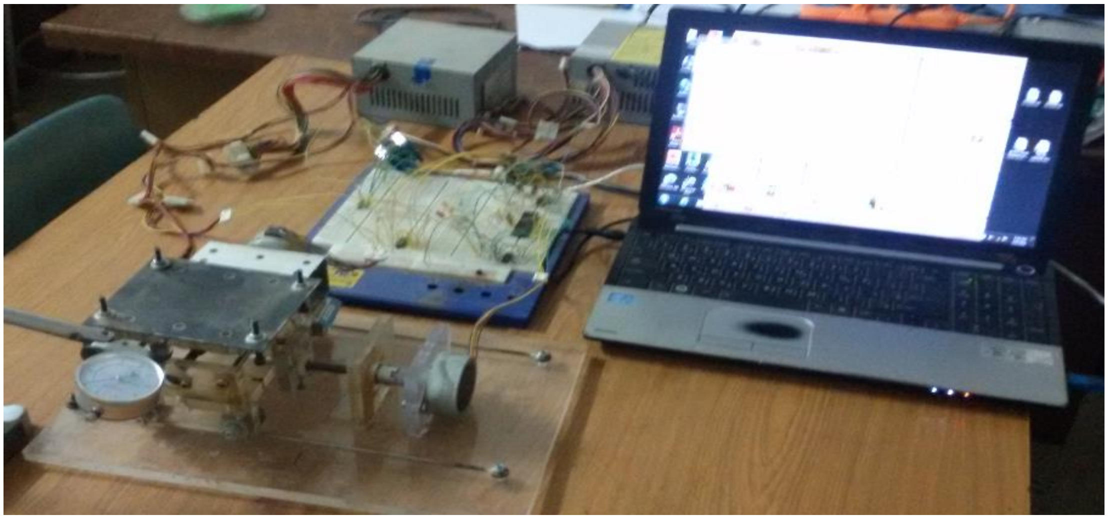


Figure 3. 25 The final selected control system

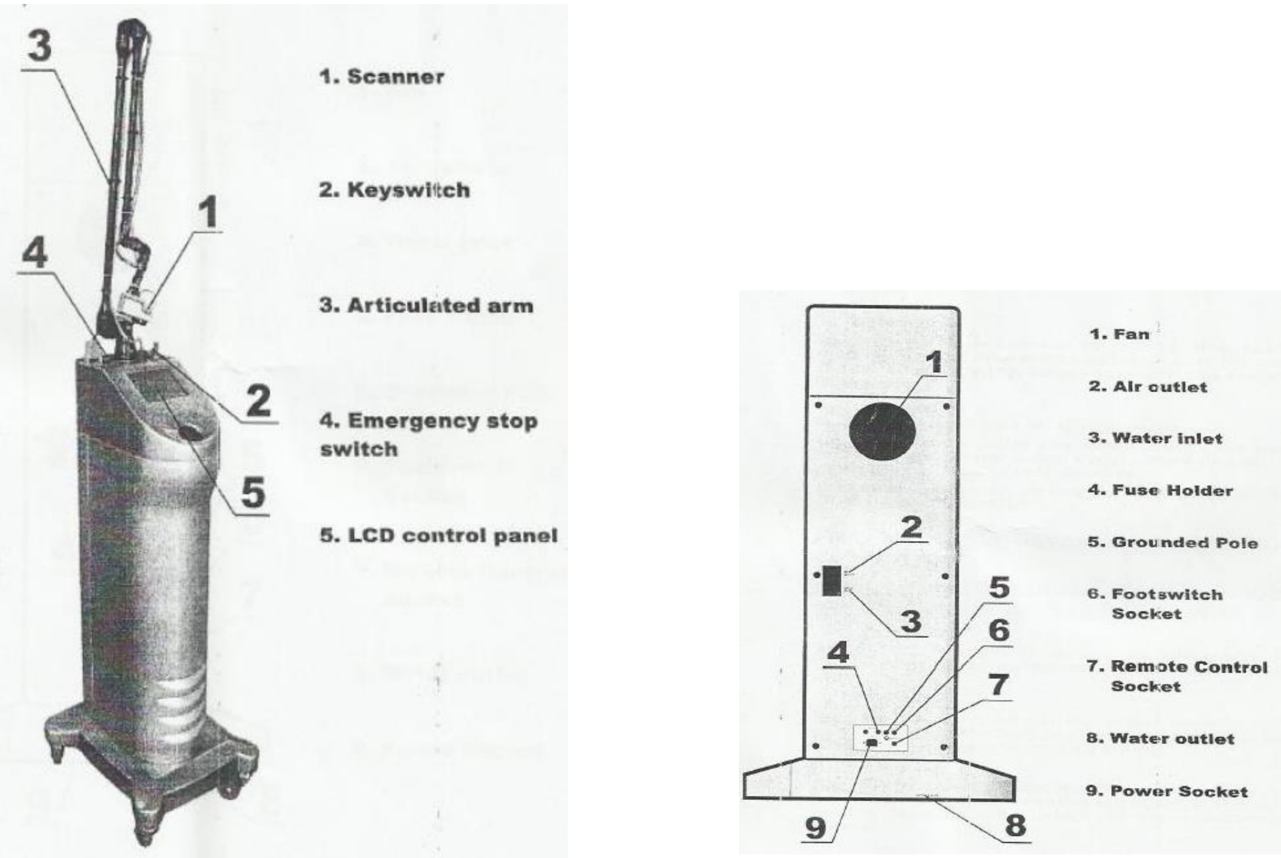
3.5 The CO_2 laser system:

The laser system controlled by the CNC system was 30W CO_2 laser surgical system model IB-601B.

The IB-601B is a CO_2 laser, with specific wavelength of 10.6 µm, with microprocessor-controlled instrument based on a sealed-off. It is safe to operate.

The laser system composed of CO_2 laser source, switch, main control panel, cooling system, foot switch and articulated arm. Figure 3.26 below shows IB-601B CO_2 laser.

All laser system function controlled by touching the thin film switch. Time and power are displayed digitally. The working radius of the articulated arm at full extension is 110 cm (Beijing Innobri technology, 2014)



(a) (b)

Figure 3. 26 IB-601B Co2 laser (a) Front View (b) Back view

CHAPTER FOUR

System Performance and Validation

4.1 Introduction:

In this chapter a comparison between the selected control system and resent CNC control system that reviewed are going to be discussed. The results of the testing and validation of the selected system, x-y table, also are presented chapter in this section.

4.2 Selected system discussion:

All types of CNC systems have a fixed power drive system as reviewed in chapter two, literature review, which is responsible of moving the x-y table, and the tools used for material processing are interchangeable according to the processed material and the type of process. But the selected control system, CNC system, have the ability to change the power drive from pneumatic actuator to electric stepper motor in the y-axis to get the high speed (more than 395 mm/s) or low speed (less than 3.2 mm/s) according to the need of the user to process material. The change from pneumatic system to electric system, as a power drive, can be done easily by untie only two screw in the slotted rectangular plate as shown in figure 4.1 below.

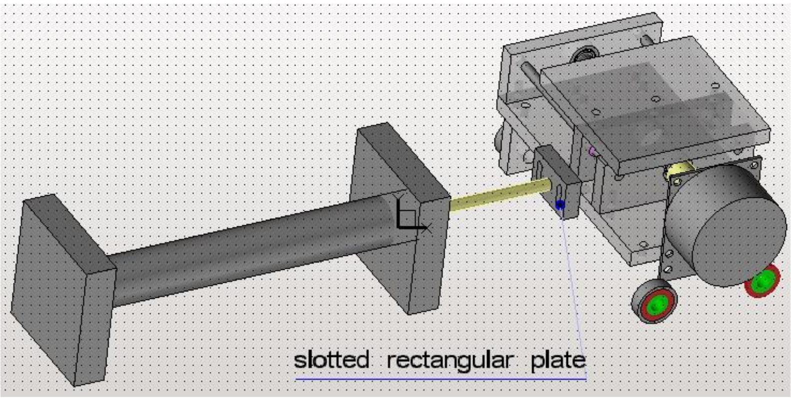


Figure 4. 1 Slotted rectangular plate

In addition, the selected x-y table can be used to process materials with a different types of lasers. This capability of attaching the x-y table to two types of power drive implies to minimize the weight of x-y table which affected the compactness and rigidity of the x-y table. In spite of that, it is possible to say that the selected system is so flexible.

Most of the recent CNC systems that used stepper motor, have step angle between (0.75°-3.6°) as in CNC prototype which is designed by Paulo A with step angle 1.8°. But in the selected system the step angle was 7.5° which minimize the resolution. If a stepper motor with small step angle is used, a high resolution can be obtained.

Also most CNC machines used trapezoid, acme thread or ball screw as a power screw. But in the selected system a fastener screw was used which increased the required torque to move the x-y table. See figure 3.20 in chapter three.

The coupling between the stepper motor and the power screw was Oldham coupling type as illustrated in chapter three. Fig. (4.2) shows the oldham coupling.

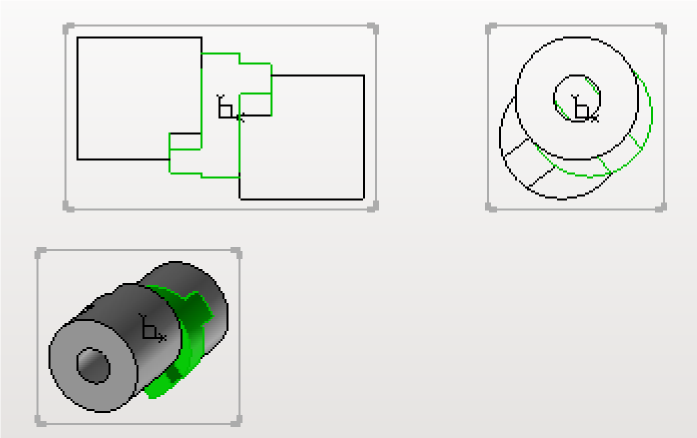


Figure 4. 2 The Oldham coupling

This Oldham coupling was selected because it has more capability than other flexible couplings to correct miss-alinement and manufacturing errors. It should be manufactured carefully because it has only two perpendicular slides and slide way which need clearance to work properly. If the dimensions of the Oldham slide and slide way are not manufactured to the required tolerances, backlash error will appear. Figure 4.3 below shows the coupling used in the CNC system.

Figure 4. 3 Flexible coupling

The selected rails were suitable and same as that used by Ravi Kumar R in his portable Laser bot system.

The selected electronic system have basic components to control the stepper motor compared to the Kernel electronic system.

The software program, which has been created using LabVIEW read a G-code and written in a text file, notepad, and send it to the Microcontroller. No possibility of simulation and dry run for the G-code program before it is executed as in Kernel CNC software. Also there is no possibility to generate G-code from drawing. All of these may weaken the software used to control the selected control system, x-y table. But it is possible to add all of those things because the used program is open.

The selected stepper motor have 7.5° step angle with 20 µm resolution was not connoted because the used laser have spot size 0.25 mm. This means that the selected numerical control system is suitable to be used with laser spot size up to 20 µm.

4.3 The results of control system test and validation:

The control system has been tested to be validate. The test was done using two methods. In the first test the x-y table was used to move polymethyl methacrylate, PMMA, sheets of 1000x100x2 mm under irradiation of CO_2 laser to engrave micro-channels resemble black body cavities. Five colors of PMMA were chosen for this purpose, namely red, green, blue, black and white sheets, RGB kW laser power 30, 25, 20 and 15 Watts, beside 1, 2, 3 and 4 laser passes were also chosen to give combinations of 35 with samples different in parameters. This test has been done by the researcher Mohammedi Hassan for degree of doctor of philosophy (Mohammedi, 2015). The samples and test was as following:

1- Acrylic sheets with colors of: red, green, blue, black and white were chosen to represent the RGB model of colors, together with the white to represent additive coloration of the RGB. Black was chosen to represent the addition of the subtractive coloration.

2- Samples were coded according to colors, laser power, and number of passes. The code indicates the colors of the sheet, power used, and number of passes, e.g., code number R30W3P, means that the color is red, power is 30 Watt and passes are 3. Samples marked STD means standard samples without micromachining process, RSTD means standard red sample.

3- The parameters used for temperature comparison between the machined and standard samples were chosen to be color, laser power of 30, 25, and 15 Watt, and the number of laser passes per fixed laser power of 30 Watt to be 1, 2, 3, and 4 passes. The repeated pulse mode of the laser was chosen for the micromachining process.

4- Time delay between the in-stroke and out-stroke of the double acting cylinder rod was chosen to be 3 seconds (Mohammedi, 2015).

Table 4.1 below lists the results obtained by the selected control system.

Table 4. 1 The PMMA samples and laser parameters used in the experimental work

Serial Number	Sample Code	Sample color	Laser Power (W)	No. of Laser Passes	Idle Time (s)	Duty Time (s)
1	RSTD	RED	0	0	0	0
2	R30W1P	RED	30	1	0.01	0.99
3	R30W2P	RED	30	2	0.01	0.99
4	R30W3P	RED	30	3	0.01	0.99
5	R30W4P	RED	30	4	0.01	0.99
6	R25W1P	RED	25	1	0.01	0.99
7	R20W1P	RED	20	1	0.01	0.99
8	R15W1P	RED	15	1	0.01	0.99
9	GSTD	GREEN	0	0	0	0
10	G30W1P	GREEN	30	1	0.01	0.99
11	G30W2P	GREEN	30	2	0.01	0.99
12	G30W3P	GREEN	30	3	0.01	0.99
13	G30W4P	GREEN	30	4	0.01	0.99
14	G25W1P	GREEN	25	1	0.01	0.99
15	G20W1P	GREEN	20	1	0.01	0.99
16	G15W1P	GREEN	15	1	0.01	0.99

17	BSTD	BLUE	0	0	0	0
18	B30W1P	BLUE	30	1	0.01	0.99
19	B30W2P	BLUE	30	2	0.01	0.99
20	B30W3P	BLUE	30	3	0.01	0.99
21	B30W4P	BLUE	30	4	0.01	0.99
22	B30W1P	BLUE	25	1	0.01	0.99
23	B30W1P	BLUE	20	1	0.01	0.99
24	B30W1P	BLUE	15	1	0.01	0.99
25	WSTD	WHITE	0	0	0	0
26	W30W1P	WHITE	30	1	0.01	0.99
27	W30W2P	WHITE	30	2	0.01	0.99
28	W30W3P	WHITE	30	3	0.01	0.99
29	W30W4P	WHITE	30	4	0.01	0.99
30	W25W1P	WHITE	25	1	0.01	0.99
31	W20W1P	WHITE	20	1	0.01	0.99
32	W15W1P	WHITE	15	1	0.01	0.99
33	KSTD	BLACK	0	0	0	0
34	K30W1P	BLACK	30	1	0.01	0.99
35	K30W2P	BLACK	30	2	0.01	0.99
36	K30W3P	BLACK	30	3	0.01	0.99
37	K30W4P	BLACK	30	4	0.01	0.99
38	K25W1P	BLACK	25	1	0.01	0.99
39	K20W1P	BLACK	20	1	0.01	0.99
40	K15W1P	BLACK	15	1	0.01	0.99

Table 4. 2 Micromachining line spacing

Theoretical line spacing (mm)	Measured line spacing							
1	0.990	1.005	0.995	1.000	1.000	0.995	1.000	1.005
0.75	0.750	0.755	0.780	0.705	0.715	0.780	0.810	0.705
0.5	0.500	0.445	0.555	0.455	0.450	0.595	0.570	0.420

Figure 4. 4 Tool maker microscope

Micro-machining line spacing was measured using tool microscope which is shown in figure 4.4.

Table 4.2 shows the spacing distance between the micromachining lines. The theoretical distance spacing 1, 0.75, 0.5 mm. For 1 mm spacing the error was ± 0.005 mm which is fine error. For 0.75 mm spacing the error was in the range of ± 0.05 mm. Also for 0.5 mm spacing the error was ±

0.05 mm. The error variation was due to the heat effect. So the guarantee accuracy is ± 0.05 mm.

According to ISO 230-2:1997 for machine tools the required accuracy for CNC machine is 0.0096 mm (0.004-0.0055) mm (Indian Standard, 2002). From the test done the accuracy of machining above 1 mm spacing is within the required standard. But the machining below 1 mm spacing is out of the ISO standard. The low accuracy of micromachining line spacing less than 1 mm was due to thermal effect of the laser beam, which has spot size equal to 0.25 mm.

The second test was the repeatability test for the x-axis and y-axis to check if the selected control system will be stopped exactly at the same position or not. Dial gauge was fixed and attached to the x-axis and the y-axis as shown in figure 4.5 and 4.6 below.

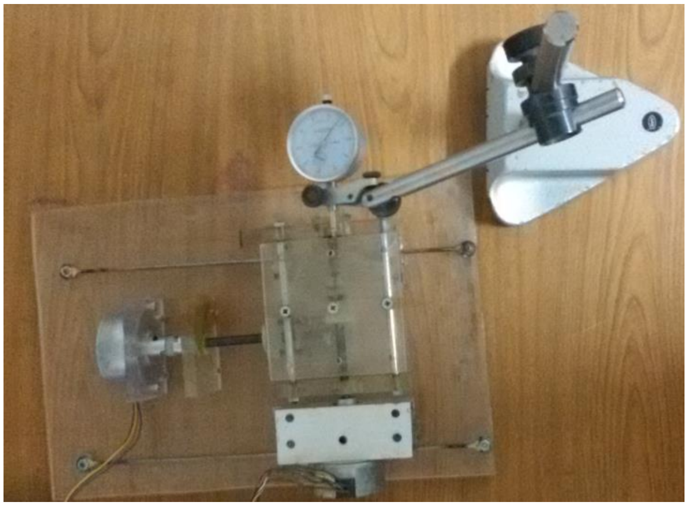


Figure 4. 5 The dial gauge attached to the x-axis

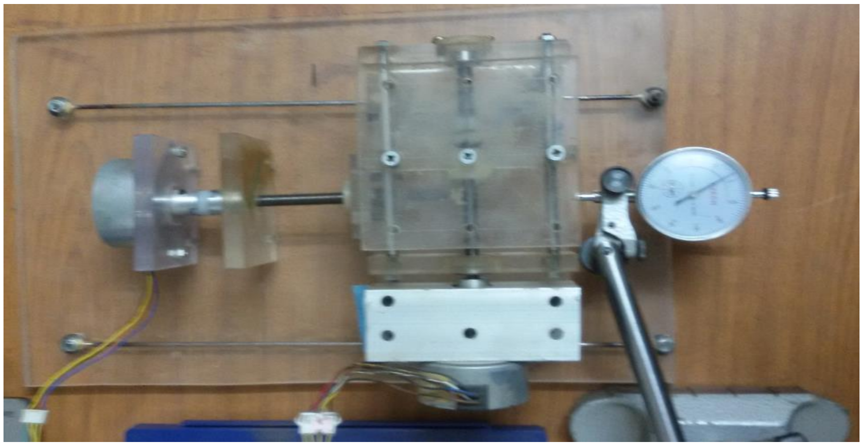


Figure 4. 6 The dial gauge attached to the y-axis

Each of the x-axis and the y-axis was moved forward and reversed 5 times for the distances 10, 20, 30 mm and the error was registered at the tables as shown below.

Table 4. 3 The x-axis offset for 10 mm length

Test No.	Accumulated error	One cycle error
1	-0.0125	-0.0125
2	-0.0150	-0.0025
3	-0.0175	-0.0025
4	-0.0200	-0.0025
5	-0.0150	+0.0050

Table 4. 4 The x-axis offset for 20 mm length

Test No.	Accumulated error	One cycle error
1	0.0000	0.0000
2	-0.0025	-0.0025
3	0.0000	+0.0025
4	-0.0025	-0.0025
5	-0.0050	-0.0025

Table 4. 5 The x-axis offset for 30 mm length

Test No.	Accumulated error	One cycle error
1	-0.0025	-0.0025
2	-0.0050	-0.0025
3	0.0000	+0.0050
4	-0.0025	-0.0025
5	-0.0050	-0.0025

Table 4. 6 The y-axis offset for 10 mm length

Test No.	Accumulated error	One cycle error
1	-0.0025	-0.0025
2	-0.0025	0.0000
3	-0.0050	-0.0025
4	-0.0025	+0.0025
5	-0.0025	0.0000

Table 4. 7 The y-axis offset for 20 mm length

Test No.	Accumulated error	One cycle error
1	-0.0025	-0.0025
2	-0.0075	-0.0050
3	-0.0100	-0.0025
4	-0.0100	0.0000
5	-0.0125	-0.0025

Table 4. 8 The y-axis offset for 30 mm length

Test No.	Accumulated error	One cycle error
1	+0.0050	+0.0050
2	0.0100	+0.0050
3	+0.0075	-0.0025
4	+0.0075	0.0000
5	+0.0050	-0.0025

Tables 4.3 to 4.8 illustrate the results of the second test. In table 4.3 one can noticed that the error in one cycle lied between +0.005 and -0.0125 mm.

Table 4.4 lists the x-axis offset for 20 mm length. The one cycle error was just 0.0025 mm which is a fine result.

Table 4.5 also lists the x-axis offset for 30 mm length. The one cycle error for the four readings was just 0.0025 mm. The abnormal reading +0.005 mm was due to the repeatability error of the dial gauge.

Tables 4.6 to 4.8 list the y-axis offset for 10, 20, 30 mm length. The one cycle error was 0.0025 mm. the abnormal reading also was due to the repeatability error of the dial gauge.

From all offset error reading for the control system, x-y table, the x-axis and the y-axis stop at start point in the return cycle with repeatability errors ± 0.0025 mm. According to ISO 230-2:1997 for machine tools the required repeatability for CNC machine is 0.0065 mm (Indian Standard, 2002). From the test done the repeatability of machining is within the required standard.

The repeatability results indicate that the electronic circuit, the software and the serial communication system all of them work together at a full compatibility, which mean that the selection is the best. The individual component was not always selection the best, but to get the best system performance. So the best numerical control system was selected.

4.4 Conclusions:

From the obtained results one can conclude that:

1- The Best selection of the control system, CNC system, for laser material processing has been achieved.
2- The selected system is flexible because it can be attached to two types of power drive.
3- The repeatability error of the x-y table is ± 0.0025 mm.
4- Machining guarantee accuracy is ± 0.05 mm.
5- A guide rod and roller bearing has been selected as x and y railing.
6- Bipolar stepper motor with 48.6 g.cm holding torque and 7.5^o step angle showed efficient performance.

4.5 Recommendations:

For the future work, the followings are recommended:

1- Stepper motor with small step angle can be used, which can control the system more accuracy.
2- Limit switch can be added to the system for protection from over shooting.
3- Addition of circular interpolation will enable the control system to process circles more smooth.
4- Addition of G-code like G40, G41and G42 will make the programming more flexible and the machining accuracy will be increased.
5- Zener diode can be used to prevent the electronic circuit from the back current.
6- The designed system can be used with Nd-YAG laser or diode laser.

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