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تصميم وتنفيذ آلة ثقب دقيقة مبنية على المتحكمات الدقيقة

Design and Implementation of Microcontroller Based Accurate Drilling Machine

A thesis Submitted in Partial Fulfillment of the Requirement for M.S.c Degree in Mechatronic Engineering

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الأيـــــة

قال الله تعالى:

{ اقرأ باسمِ ربّكَ الَّذي خلَق (1) خلَقَ الإنسانَ من علَق (2) اقرأ وربُّكَ الأكرم (3) الَّذي علَّمَ بالقلَم (4) علَّم الإنسانَ ما لم يعلم (5) }

العلق

Dedication

I dedicate this project to God Almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. He has been the source of my strength throughout this program and on His wings only have I soared .Also I am grateful to some people, who worked hard with me from the beginning till the completion of the present research particularly my supervisor Dr. Abdalrsoal who has been always generous during all phases of the research.

Although he is no longer of this world, his memories continue to regulate my life. May Allah (SWT) grant you Jannah Firdaws. I sincere appreciation also goes to my supervisor Dr. Aladdin Awdah whose contribution and constructive criticism has pushed me to expend the kind of efforts I have exerted to make this work as original as it can be. Thanks to him I have experienced true research and my knowledge on the subject matter has been broadened.

I also would like to express my wholehearted thanks to my family for their generous support they provided me throughout my entire life and particularly through the process of pursuing the master degree.

Acknowledgement

In the name of Allah, the Most Gracious and the Most Merciful Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this thesis.

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O Allaah , I ask you by your mercy which envelopes all things , that you forgive Dr .Abdalrsoal ,
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Table of Contents

List of Figures

List of Tables

List of Abbreviations

ADC	Analogue to Digital Conversion
CAD	Computer Aided Design
CPU	Central Processing Unit
CW	Continuous Wave
DPSS	Diode Pumped Solid State Lasers
DAC	Digital to Analogue Conversion
EPROM	Electrically Programmable Read Only Memory
EEPROM	Electrically Erasable Read Only Memory
EDM	Electrical Discharge Machining
E	Electric Field
H	Magnetic Field
I/O	Input and Output
IDE	Integrated Development Environment
KDP	Potassium Dihydrogen Phosphate
LMP	Laser Material Processing
LED	Light Emitting Diodes
Nd : YAG	Neodymium Doped Yttrium Aluminum Garnet
PM	Permanent Magnet
RAM	Random Access Memory
ROM	Read Only Memory
SSR	Solid State Relay
TEM	Transverse Electromagnetic
USB	Universal Serial Bus

المستخلص

الهدف من هذه البحث هو تصميم آلة حفر ثقوب دقيقة عن طريق استخدام متحكم اردوينو واستخدام محركات الخطوة للحركة الميكانيكية واستخدام تقنيات الليزر للثقب هذا التصميم يتم ربطه بجهاز حاسوب عن طريق وصلة البيانات .

للموائمة قمنا بتثبيت برنامج بيئة التطوير المتكاملة الخاص بمتحكم الاردوينو في جهاز الحاسوب واستخدامه لإنشاء وإرسال البيانات إلى متحكم اردوينو، وللسيطرة على التصميم من خلال ارسال بيانات موقع الثقب على وصلة البيانات .

تظهر النتائج ان التصميم قادر على عمل ثقوب مختلفة بدقة عالية وفقا لتلقي بيانات موقع الثقب كما ان التصميم لديه العديد من المزايا مقارنة مع اجهزة الثقب التقليدية.

Abstract

The aim of this thesis is to design an accurate drilling machine by use Arduino microcontroller and geared stepper motors for mechanical movement and use laser techniques for drilling. This design connected to a personal computer by serial communication.

For interfacing we installed integrated development environment program in personal computer and used to compose and send data to the Arduino board, and control the design by sending drill position data through serial monitor**.**

The result shows that the design is able to make different accurate holes according to receiving drill position data, and the design has more advantages than traditional drilling machines.

Chapter I
Introduction

1.1 Basics of Drilling Machines:

A drilling machine is one of the most important machine tools in a workshop. It was designed to produce a cylindrical hole of required diameter and depth on metal work pieces. Though holes can be made by different machine tools in a shop, a drilling machine is designed specifically to perform the operation of drilling and similar operations.

Drilling can be done easily at a low cost in a shorter period of time in a drilling machine. Drilling can be called as the operation of producing a cylindrical hole of required diameter and depth by removing metal by the rotating edges of a drill. The cutting tool known as drill is fitted into the spindle of the drilling machine.

A mark of indentation is made at the required location with a center punch. The rotating drill is pressed at the location and is fed into the work. The hole can be made up to a required depth and also the Drilling machines may be used to perform other operations. They can perform countersinking, boring, counter boring, spot facing reaming, and tapping. Drill press operators must know how to set up the work, set speed and feed, and provide for coolant to get an acceptable finished product.

The size or capacity of the drilling machine is usually determined by the largest piece of stock that can be center drilled. For instance, a 15-inch drilling machine can center-drill a 30-inch-diameter piece of stock. Other ways to determine the size of the drill press are by the largest hole that can be drilled, the distance between the spindle and column, and the vertical distance between the worktable and spindle.

1.2 The Operation of Drilling Machines:

In those shops where the most remarkable improvement has been made in rates of production secured on drilling machines, the increase has been largely due to constantly higher speeds and the rates of feed which are employed in the performance of drilling operations, but more particularly as a result of increasing the speed.

There are many noteworthy advantages secured through drilling at high speed, the remarkable increase in the speed at which drilling operations are performed has created a condition which was formerly unimportant, i.e., in regard to the relation between the time actually consumed in the performance of a drilling operation and the time required for setting up the work. Obviously, increasing the speed and rate of feed cuts down the time required to drill a hole, and, therefore, jigs and work-holding fixtures must be so constructed that the setting-up time does not become the limiting factor in performing the drilling operation.

The steps which must be taken to secure this result will vary according to the depth of the hole, and consequently according to the time required to complete the drilling operation.

In any case, the chief points which require consideration are to design jigs and fixtures with clamping devices which

may be quickly operated, so that the minimum amount of time is required to secure the work in place ready to be drilled, or to provide jigs or fixtures of the so-called indexing type, so that the operator may be setting up a piece in the fixture while the machine is engaged in drilling work held in other sections of the fixture.

1.3 Problem Statement:

Human force mostly is required to drill the hole, drilling depth cannot be estimated properly, job may spoil due to human errors, and different size holes cannot be drilled without changing the drill bit. Consumes lot of time for doing repeated multiple jobs, these all are the drawbacks and if we need cut off piece to smallest size then we need additional machine.

1.4 Proposed Solution:

To overcome all these problems, this automated drilling machine is designed which is aimed to drill the holes automatically over a job according to the drilling position data programmed through a keyboard by using laser technique and get accurate results also it can be cut off any piece to small size without change the machine to another by using laser technique.

1.5 Objective:

The objective of these project is Doing very accurate holes with the possibility of cutting materials through controlling of two steeper motor by using microcontroller that is connected to personal computer to take data of the job.

1.6 Methodology:

1.6.1 Laser Drilling and its Techniques:

Drilling is one of the most important and successful applications of industrial lasers. Laser drilling emerges as a viable and successful substitute for holes less than 0.25mm in diameter that are otherwise difficult to drill mechanically, especially for hard and brittle materials, such as ceramics and gemstones.

Laser drilling of metals is used to produce tiny orifices for nozzles, cooling channels in air turbine blades, etc. For direct hole drilling, the quality of the laser beam, wavelength, intensity, pulse duration, pulse repetition rate are all important parameters. Yet many issues remain to be solved when high quality holes are to be drilled in various material.

Laser is the acronym of Light Amplification by stimulated emission of radiation. Laser is light of special properties, being very different from normal light in that it is coherent having low beam divergence and high energy content, and thus creates heat upon striking a surface. This heat is utilized in machining of various kinds of material.

Laser machining means material removal accomplished by laser material interaction. What it does is use ultra-fast laser pulses of very short duration to remove material in layers from the surface of the work piece.

Machining depths per layer vary from one application to another. Generally speaking, Laser Machining processes include laser drilling, laser cutting and laser grooving, marking or scribing.

Laser machining is not programmed like traditional cutting/milling equipment requiring speeds and feeds, but instead is driven directly from digital Computer-aided design (CAD) data.

Laser drilling is one of the oldest applications of laser machining processes. a well-known example of laser drilling is the drilling of airfoil cooling holes in components of aircraft engines. Another application is drilling holes for fuel filters for automobile manufacturing.

Laser hole drilling in ceramic, silicon and polymer substrates is widely used in electronics industry. Usually Nd : YAG (neodymium-doped yttrium aluminum garnet; Nd:Y3Al5O12) lasers with pulse length of several tenths of milliseconds are used to drill such holes when a certain degree of inaccuracy of diameter and shape as well as thin recast layer can be tolerated. In cases where higher accuracy is required, laser drilling with millisecond pulses does not meet the requirement. The means to increase precision then include reduction of pulse length and improvable of machining techniques.

1.6.2 Stepper Motors and its Structure:

Stepper motors are, in effect, DC motors with a twist. Instead of being powered by a continuous flow of current, as with regular DC motors, they are driven by pulses of electricity. Each pulse drives the shaft of the motor a little bit. The more pulses that are fed to the motor, the more the shaft turns.

Then it special type of DC motor No commutator windings part of stator and can be unipolar (one power supply) or bipolar (two power supplies) and it can be rotating both clockwise (CW) and anticlockwise (CCW) and the Rotates in precise angular increments called ‘steps’ and sustains holding torque at zero speed and it can be controlled to ‘step’ with better resolution than the manufactured resolution.

1.6.3 Microcontrollers:

A microcontroller is a computer with most of the necessary support chips on board. All computers have several things in common, namely:

i. A central processing unit (CPU) that ‘executes’ programs.

ii. Some random-access memory (RAM) where it can store data that is variable.

iii. Some read only memory(ROM)where programs to be executed can be stored.

iv. Input and output (I/O) devices that enable communication to be established with the outside world i.e. connection to devices such as keyboard, mouse monitors and other peripherals.

There are a number of other common characteristics that define microcontrollers. If a computer matches a majority of these characteristics, then it can be classified as a microcontroller and it may be:

A. Embedded inside some other device (often a consumer product) so that they can control the features or actions of the product. Another name for a microcontroller is embedded controller.

B. Dedicated to one task and run one specific program. The program is stored in ROM and generally does not change.

C. A low-power device. A battery-operated microcontroller might consume as little as 50 mill watts.

A microcontroller may take an input from the device it is controlling and controls the device by sending signals to different components in the device. A microcontroller is often small and low cost. The components may be chosen to minimize size and to be as inexpensive as possible.

The actual processor used to implement a microcontroller can vary widely. In many products, such as microwave ovens, the demand on the CPU is fairly low and price is an important consideration. In these cases, manufacturers turn to dedicated microcontroller chips devices that were originally designed to be low-cost, small, low-power, embedded CPUs. The Motorola 6811 and Intel 8051 are both good examples of such chips.

A typical low-end microcontroller chip might have 1000 bytes of ROM and 20 bytes of RAM on the chip, along with eight I/O pins. In large quantities, the cost of these chips can sometimes be just a few pence.

1.7 Research outline:

In chapter one will discuss the background about the research.

In chapter two will discuss the literature review of the research.

In chapter three will discuss the hardware component and electrical circuit design of the research.

In chapter four will discuss the software for the circuit of the research.

In chapter five will discuss the results and discussion of the research.

In chapter six will discuss the conclusion and recommendation of the research.

Chapter II
Literature review

2.1 Drilling Machine:

Drilling is one of the basic machining process of making holes and it is essentially for manufacturing industry like Aerospace industry, watch manufacturing industry, Automobile industry, medical industries and semiconductors. Especially Drilling is necessary in industries for assembly related to mechanical fasteners. It is reported that around 55000 holes are drilled as a complete single unit production of the Air bus A350 aircraft.

Simple drilling machines like hand held portable drilling machines, power feed drilling machines, etc. are quite common, we can find these machines everywhere. Often these machines are used for drilling a through hole over the job; these machines cannot be used for number of machining operations for specific applications. Human force is required to drill the hole.

Study on different drilling machine and using different drill techniques which are mechanical drilling types or laser types. The review consists of papers from different journals which are also mentioned at adequate places.

G.niranjan , a.chandini , p.mamatha designing electrical drilling machine that quite useful for mechanical workshops. The machine is constructed with power feed technology is aimed to drill the job up to certain specified depth, For ex: if a particular piece of job is supposed to be drilled to a limited depth, doi mechanical movements are restricted by programming the drilling depth through a potentiometer interfaced with microcontroller [1].

Sushant dhar, nishant saini, r. purohit , discuss the drilling as one of the most important and successful applications of industrial lasers. Laser drilling emerges as a viable and successful substitute for holes less than 0.25mm in diameter that are otherwise difficult to drill mechanically especially for hard and brittle materials, such as ceramics and gemstones.

Laser drilling of metals is used to produce tiny orifices for nozzles, cooling channels in air turbine blades, etc.For direct hole drilling, the quality of the laser beam, wavelength, intensity, pulse duration, pulse repetition rate are all important parameters.

Yet many issues remain to be solved when high quality holes are to be drilled in various material. These include cracks, large taper size, unsatisfactory shape etc. and their paper is discuss the technologies, applications and techniques that lead to the solution of aforesaid problems are highlighted [2].

Jeffrey thesis attempts to advance the understanding of laser drilling variation sources on gas turbine nickel-based alloy blades and vanes. It also illustrates the importance of a disciplined approach to reducing variation in advanced manufacturing processes.

For illustrative purposes, his thesis consists of two main sections. The first focuses on efforts to reduce laser drilling variation. A historical view of the process highlights the need for a rigorous improvement plan.

A disciplined approach is then proposed, incorporating a variety of tools to focus on key issues. Finally, testing and analysis provide the quantitative insights for improving the process. Rigorous test data showed the drilling process to be significantly impacted by energy and focus variations.

The sensitivity was greater than anticipated and highlights the need for improved setup techniques and instrumentation for successful production runs. The second section of the thesis takes an organizational perspective of managing process improvement knowledge.

The historical perspective shows that there were not sufficient systems in place to facilitate the necessary learning. The three key elements of acknowledge management system (creation, capture, and transfer) and the implementation of such a system are discussed [3].

This chapter of thesis explains the types of drilling machines and laser drilling techniques with all adequate detail.

2.2 Types of Classic Drilling Machines:

1. Vertical drilling machines.
2. Radial drilling machine.
3. Multiple spindle drilling machine.

Each of these general classes is capable of further subdivision so that drilling machines are finally classified under the following headings:

1. Vertical or "upright" drilling machines.
2. Vertical sensitive drilling machines.

3. Vertical high-duty drilling machines.
4. Radial drilling machine
5. Multiple-spindle drilling machines of straight –line type.
6. Multiple-spindle drilling machines of cluster type.
7. Turret type drilling machines.

In addition to the seven preceding types of machines, a great deal of useful work is done by special machines built to meet the requirements of individual cases. Such machines are generally of the multiple-spindle type, but they are especially designed for specific classes of work [4].

2.2.1 Vertical or Upright Drilling Machines:

The vertical or upright machine is the most commonly used type of (drill press) employed in the machine shop. It is usually equipped with power feed and a tapping attachment is often provided, which may be engaged to provide for handling work in which holes have to be tapped [4].

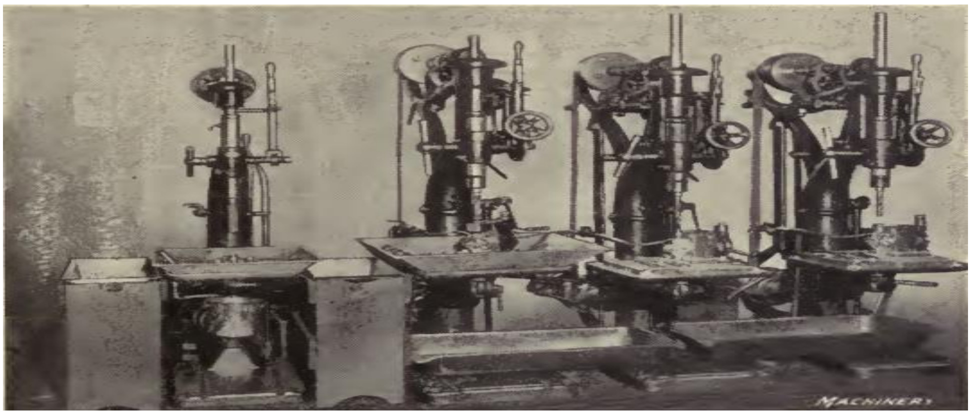

Fig.2.1 Vertical drilling machines equipped with indexing fixtures for drilling universal joint rings

2.2.2 Vertical Sensitive Drilling Machines:

The term (sensitive) is applied to those types of light drilling machines which are equipped with hand feed, so that the operator is able to judge the amount of feed pressure with which the drill is being driven into the work. These machines are usually adapted for drills from the smallest sizes up to from $_{3/8}$ to $_{7/8}$ inch in diameter.

They are used on a great variety of work, and for handling small parts in quick-acting jigs or fixtures they are capable of giving very satisfactory results. One advantage of the hand feed is that an experienced operator may use his judgment in releasing the feed pressure, if he finds that the drill has struck a hard spot in the work. This is the means of saving the breaking of drills. Machines of this type are now being built for operation at speeds which were unheard of a few years ago. For instance, some types of sensitive drilling machines are built for operation at speeds ranging from 10,000 to 15,000 revolutions per minute [4].

Fig. 2.2 Sensitive drilling machine with special jig for drilling cross holes in pins

2.2.3 Vertical High Duty Drilling Machines:

As their name implies, high-duty drilling machines are adapted for the performance of heavy work, and they are commonly employed for using a range of drill sizes running from the maximum capacity of sensitive drilling machines up to the largest sizes in which drills are made.

In addition to the performance of drilling operations, high-duty drilling machines are used for a great variety of other classes of work, including such operations as hollow-milling, spot-facing, facing, counter boring, threading, tapping, etc. In general, machines of this character may be employed to advantage wherever it is desired to use a rotating tool on stationary work under conditions where heavy cuts are to be taken [4].

To meet the requirements of such severe service, the high-duty drilling machine is equipped with power-driven feed, and the rates of feed are commonly much greater than that employed on sensitive drilling machines, while the speed at which the drill is operated is correspondingly reduced, owing to the greater diameter of the drill. There are various forms of mechanisms used on these machines, but in all cases provision is made for obtaining any of a range of speed and feed changes suitable for the work on which the machine is engaged [4].

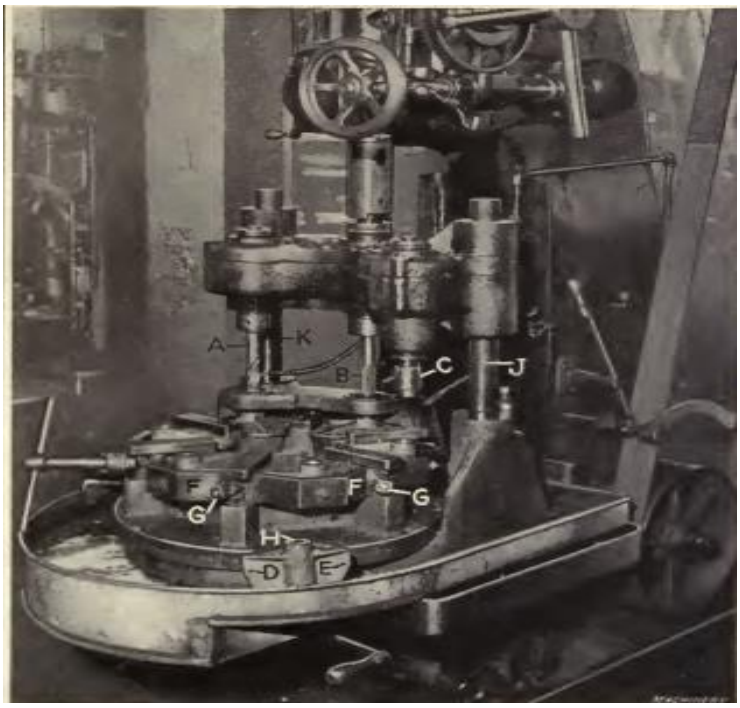

Fig. 2.3 High duty drilling machine equipped with indexing fixture and special three spindle head for drilling, reaming, and facing

2.2.4 Radial Drilling Machines:

On the familiar type of radial drilling machine, the spindle head is carried on an arm, which may be swung around the column of the machine, and the spindle head may also be moved back and forth along the arm.

This combination of movements makes it possible to locate the spindle of a radial drilling machine at any desired point over work which comes within this range of movement. Radial drilling machines are commonly classified according to the length of arm, i.e., a 6-foot radial drill has an arm 6 feet in length. Sizes in which these machines are generally built run from about 2 to 6 feet.

Obviously, the size of the work which can be handled with a machine of this type is governed by the length of arm and vertical adjustment of the arm on the machine column. Radial drilling machines are generally employed for handling those classes of work where there are a number of holes to be drilled and where the work is either too heavy or too large to be conveniently set up on multiple-spindle drilling machines [4].

Fig. 2.4 Radial Drilling Machine

2.2.5 Multiple Spindle Drilling Machines:

A great many parts that have to be drilled require holes of different diameters, and other operations, such as counter boring, reaming, or countersinking, are frequently necessary. When work of this class is done in a machine having one spindle, considerable time is wasted in removing one drill and replacing it with a different size or with some other kind of tool. For this reason, drilling machines having several spindles are often used when the work requires a number of successive operations [4].

The advantage of the multiple spindle or (gang) type as applied to work of the class mentioned is that all the different tools necessary can be inserted in the various spindles, and the drilling is done by passing the work from one spindle to the next. Drilling machines of the multiple-spindle type are also commonly used for drilling a number of holes simultaneously.

The arrangement of these machines is varied considerably to suit different kinds of work, but they may be divided into two general classes, namely, those having spindles which remain in the same plane but can be adjusted for varying the center-to center distance, and those having spindles which can be grouped in a circular, square, or irregular formation. The first class referred to is used for drilling rows of bolt or rivet holes in steel plates, etc., and the second type is adapted to the drilling of cylinder flanges, valve flanges, or similar work [4].

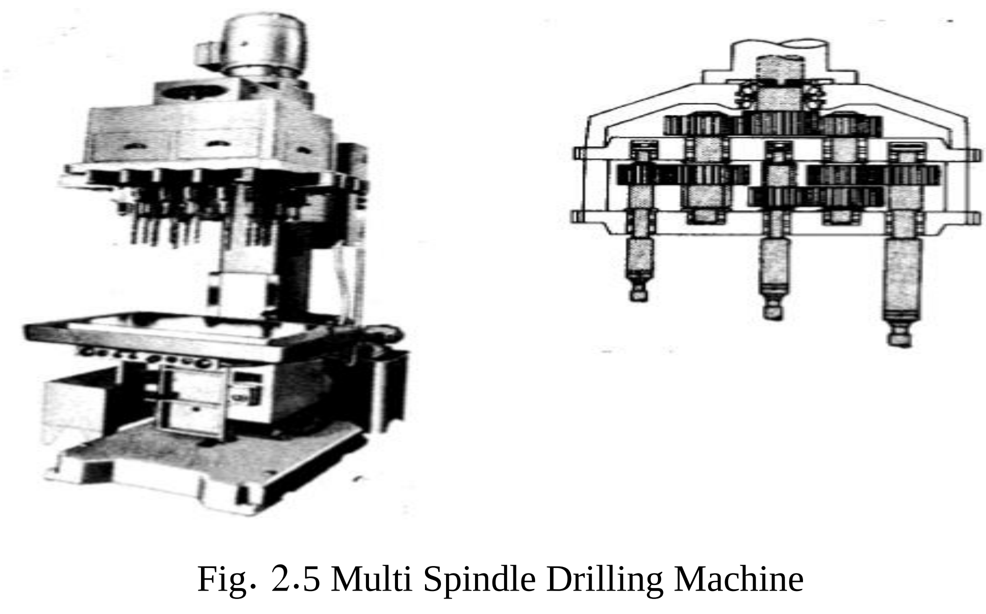

Fig. 2.5 Multi Spindle Drilling Machine

2.2.6 Turret Type of Drilling Machines:

Drilling machines of the turret type fill the same general place among drilling machines that is taken by the turret lathe among machines of that type. In other words, turret drilling machines are used in those cases where there is a sequence of such operations as drilling, counter boring, and tapping to be performed on a piece of work.

Machines of this type are equipped with a turret carried on a horizontal axis about which the turret may be revolved to bring the sequence of tools into the operating position. In general, turret-type drilling machines are used as an alternate method of handling those classes of work which are commonly handled on multiple-spindle drilling machines of the straight-line type, where work is passed along from spindle to spindle [4].

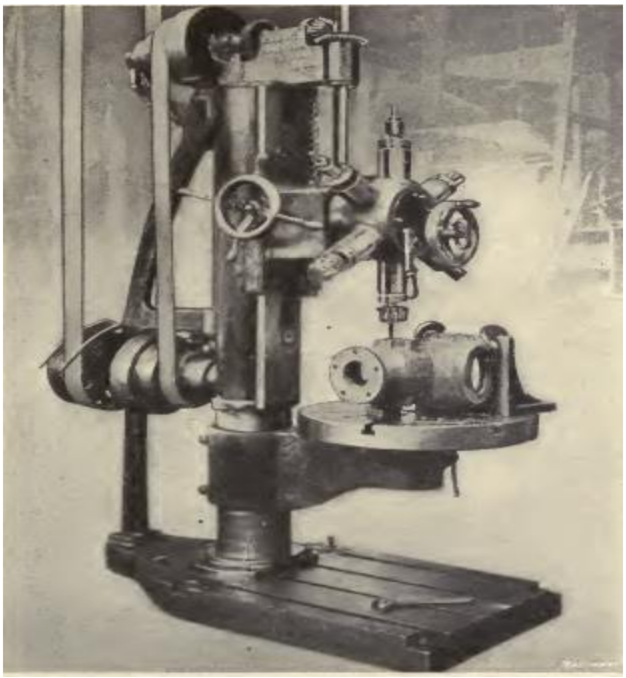

Fig. 2.6 Turret type of drilling machine in which turret revolves in vertical plane

2.3 Type of Modern Drilling Machines:

2.3.1 Hand Drilling Machines:

Unlike the classic drilling machines, the hand drill is a portable drilling device which is mostly held in hand and used at the locations where holes have to be drilled. The small and reasonably light hand drills are run by a high speed electric motor [5].

In fire hazardous areas the drill is often rotated by compressed air.

.

Fig. 2.7 Hand Drill in Operation

2.3.2 Micro (or Mini) Drilling Machines:

This type of tiny drilling machine of height within around 200 mm is placed or clamped on a table, and operated manually for drilling small holes of around 1 to 3 mm diameter in small work pieces [5].

Fig. 2.8 Micro (or mini) Drilling Machine

2.3.3 Deep Hole Drilling Machines:

Very deep holes of L/D ratio 6 to even 30, required for rifle barrels, long spindles, oil holes in shafts, bearings, connecting rods etc, are very difficult to make for slenderness of the drills and difficulties in cutting fluid application and chip removal.

Such drilling cannot be done in ordinary drilling machines and by ordinary drills. It needs machines like deep hole drilling machine such as gun drilling machines with horizontal axis which are provided with.

A. High spindle speed
B. High rigidity
C. Tool guide
D. Pressurised cutting oil for effective cooling, chip removal and lubrication at the drill tip [5].

2.4 Laser Techniques:

Laser is the acronym of light amplification by stimulated emission of radiation. Although regarded as one of the nontraditional processes, laser material processing (LMP) is not in its infancy anymore. Einstein presented the theory of stimulated emission in 1917, and the first laser was invented in 1960.

Many kinds of lasers have been developed in the past 43 years and an amazingly wide range of applications such as laser surface treatment, laser machining, data storage and communication, measurement and sensing, laser assisted chemical reaction, laser nuclear fusion, isotope separation, medical operation, and military weapons have been found for lasers. In fact, lasers have opened and continue to open more and more doors to exciting worlds for both scientific research and engineering [6].

2.4.1 Nature of Electromagnetic Radiation:

Electromagnetic radiations consist of propagating waves associated with the oscillating electric field (E) and magnetic field (H). These components oscillate at right angles to each other and also to the direction of propagation of wave. Since the magnetic field vector is perpendicular to the electric field vector, the description of the propagation of the wave generally considers the oscillation of the electric field vector only. When the oscillations of the electric field vector are in particular order, the light is said to be polarized. In a plane polarized light, the electric vector oscillates in a single plane as the wave travels.

This is illustrated in Fig. 2.9 for a wave propagating in x-direction while the electric vector is oscillating in x–y plane. In contrast, the electric vectors in the completely polarized light can assume any possible directions (i.e., electric vector oscillating randomly in more than one plane). For a plane-polarized wave shown in Fig. 2.9, the electric vector oscillating in y-direction varies with space and time.

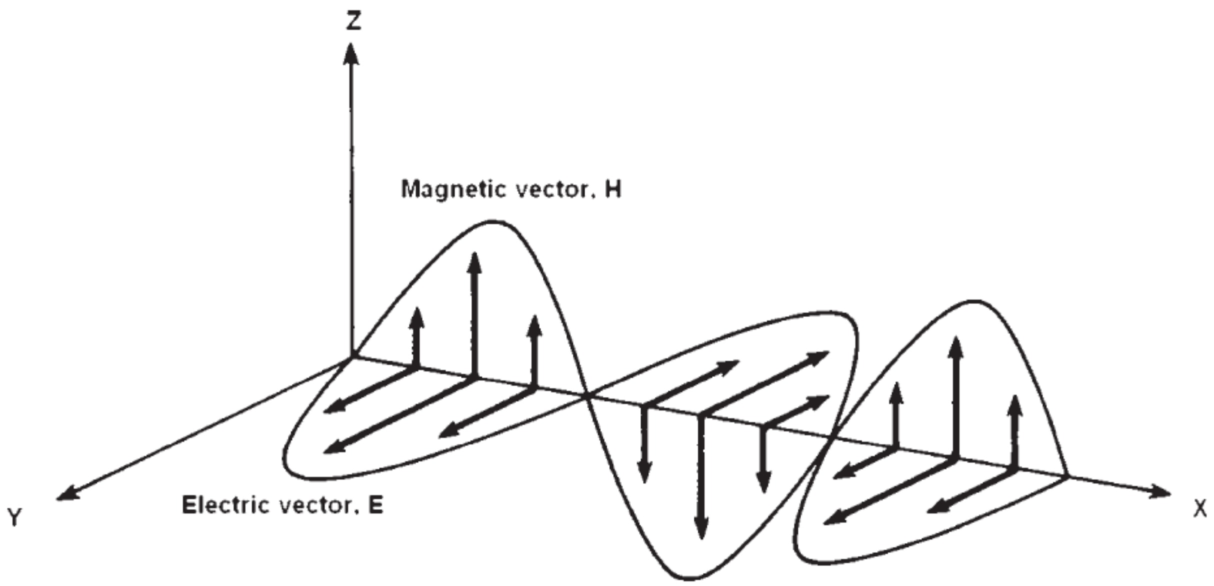

Fig. 2.9 Schematic of the oscillations of electric (E) and magnetic (H) field vectors associated with plane electromagnetic wave

For sinusoidal variation, this can be expressed as:

$$\mathbf{E} = A \sin 2\pi \left(\frac{x}{\lambda} - \nu t \right), \qquad (1)$$

Where A is the amplitude, λ is the wavelength, and V is the frequency of the wave.

The wavelength and frequency of all the electromagnetic waves exhibit a simple relationship:

$$c = n\lambda, \qquad (2)$$

where c is the velocity of light (2.9979×10^8 m/s in vacuum). The strength of the electromagnetic radiation is often described in terms of intensity of radiation. Intensity is defined as the energy per unit area perpendicular to the direction of motion of the wave and is proportional to the square of amplitude of the wave. Based on the wavelength (or frequency/energy), the electromagnetic spectrum can be divided into various regions [6].

Figure 2.10 presents the entire electromagnetic spectrum consisting of radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, x-ray, and gamma ray radiation in the order of decreasing wavelength. The description of the exact dividing wavelength between two adjacent regions in electromagnetic spectrum is difficult and hence the wavelengths of various regions are often expressed in approximate ranges [6].

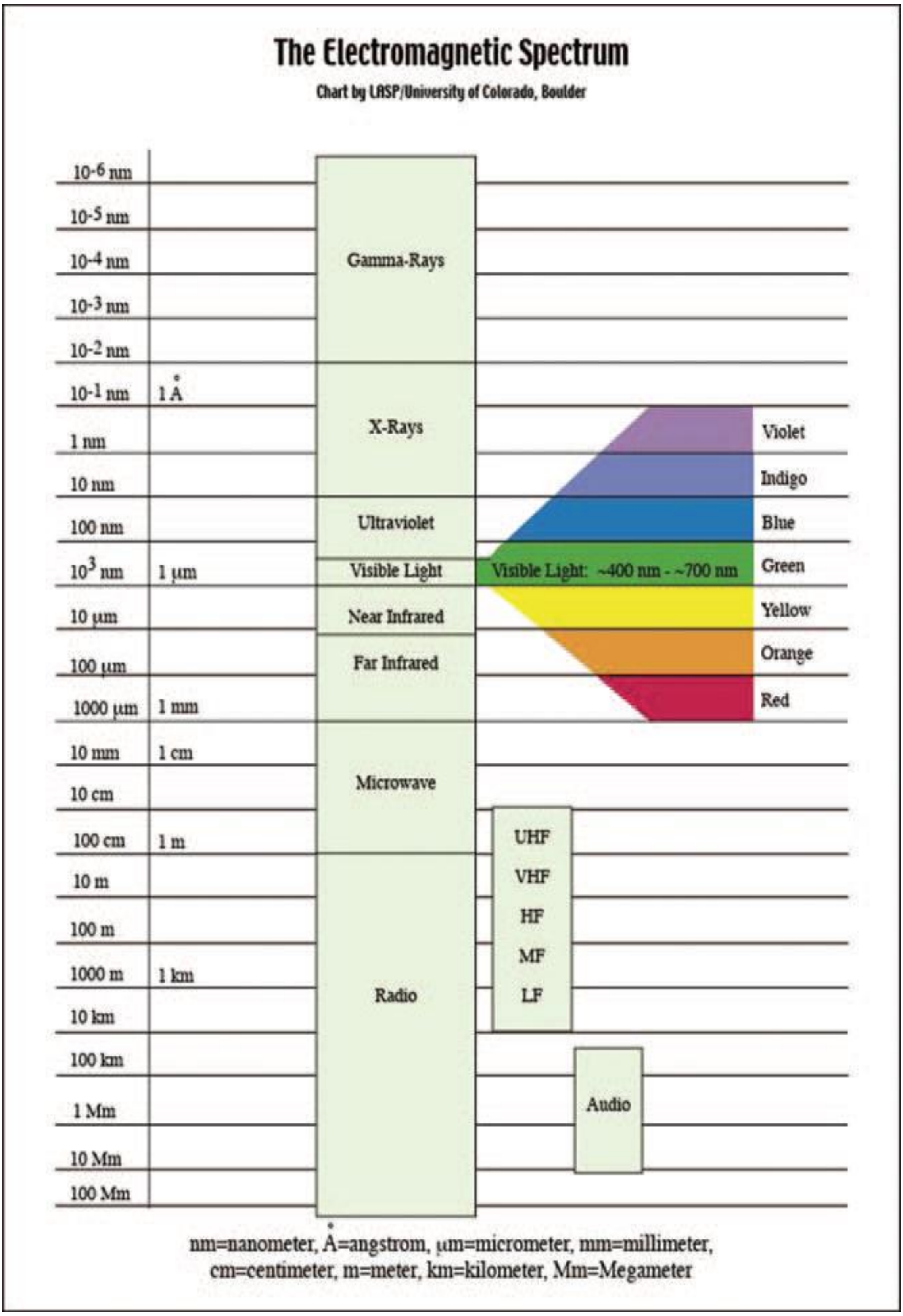

Fig. 2.10 Electromagnetic spectrum [3]

2.4.2 Laser Operation Mechanism:

Stimulated emission, the underlying concept of laser operation, was first introduced by Einstein in 1917 in one of his three papers on the quantum theory of radiation. Almost half a century later, in 1960, T.H. Maiman came up with the first working ruby laser.

The three processes required to produce the high energy laser beam are population inversion, stimulated emission, and amplification [6].

A. Population Inversion:

Population inversion is a necessary condition for stimulated emission. Without population inversion, there will be net absorption of emission instead of stimulated emission. For a material in thermal equilibrium, the distribution of electrons in various energy states is given by the Boltzmann distribution law:

$$N_2 = N_1 \exp\left[-\left(E_2 - E_1\right)/\mathrm{k}T\right] \qquad (3)$$

Where N1 and N2 are the electron densities in states 1 and 2 with energies E1 and E2 , respectively. T and k are the absolute temperature and Boltzmann constant, respectively. According to the Boltzmann law, the higher energy states are the least populated and the population of electrons in the higher energy states decreases exponentially with energy (Fig. 2.11a). Population inversion corresponds to a non equilibrium distribution of electrons such that the higher energy states have a larger number of electrons than the lower energy states (Fig. 2.11b).

The process of achieving the population inversion by exciting the electrons to the higher energy states is referred to as pumping [7].

The population inversion explained here for the two-level energy systems is only for the introduction of the concept. In actual practice, it is impossible to achieve the population inversion in two-level energy systems. Population inversion in most of the lasers generally involves three- or four-level energy levels (Fig. 2.12). For a three-level energy system, electrons are first pumped from energy level E0 to E2 by the absorption of radiation (of frequency, $\nu = (E2 - E0)/h$) from a pumping source.

The lifetime of the electrons in the higher energy level E2 is generally very short and the electrons from the energy level E2 rapidly decay into metastable energy level E1 without any radiation (radiation less decay). Thus, the net population inversion is achieved between the energy level E1 and E0, which is responsible for the

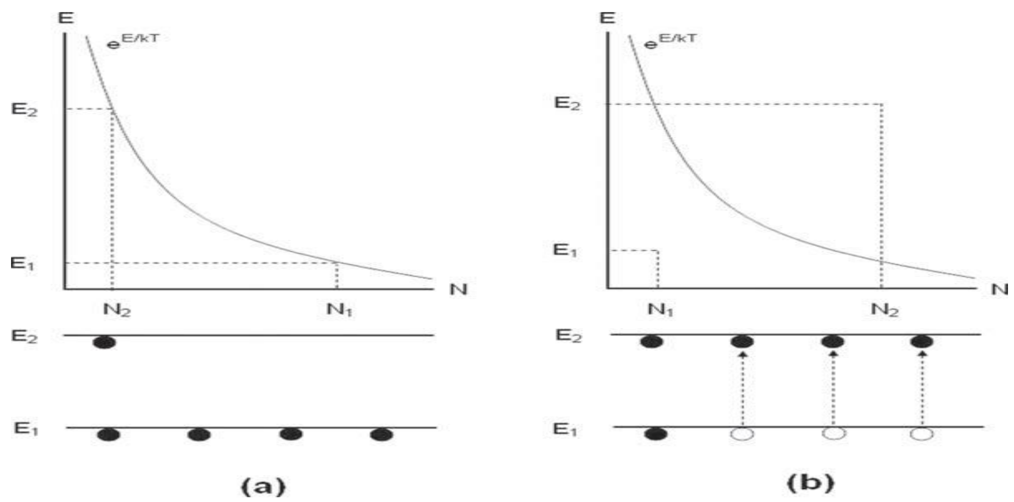

Fig. 2.11 Schematic of the population of electrons in two-level energy systems: (a) thermal equilibrium and (b) population inversion

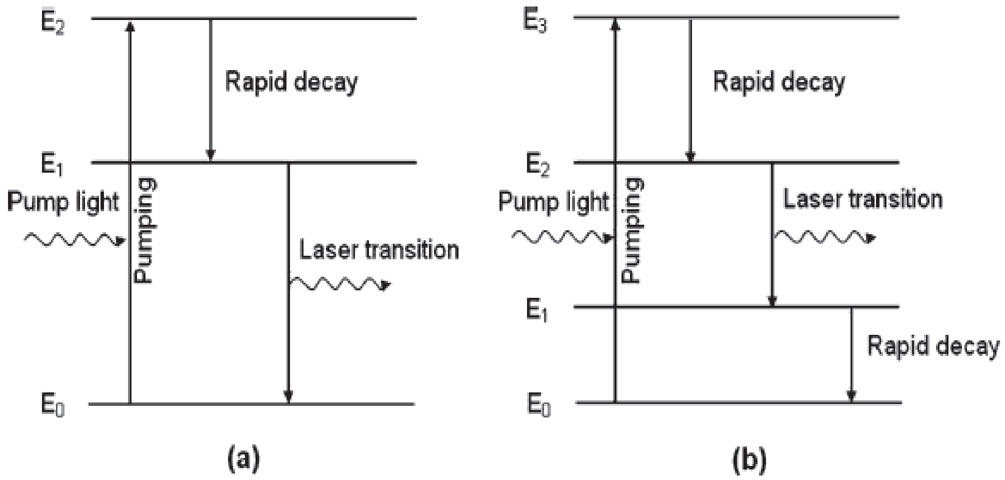

Fig. 2.12 Schematic of the population inversion in (a) three-level and (b) four-level energy laser systems

subsequent emission of laser radiation (Fig. 2.12a). Similar mechanisms cause the population inversion between the energy levels E2 and E1 in four-level energy laser systems (Fig. 2.12b) [8].

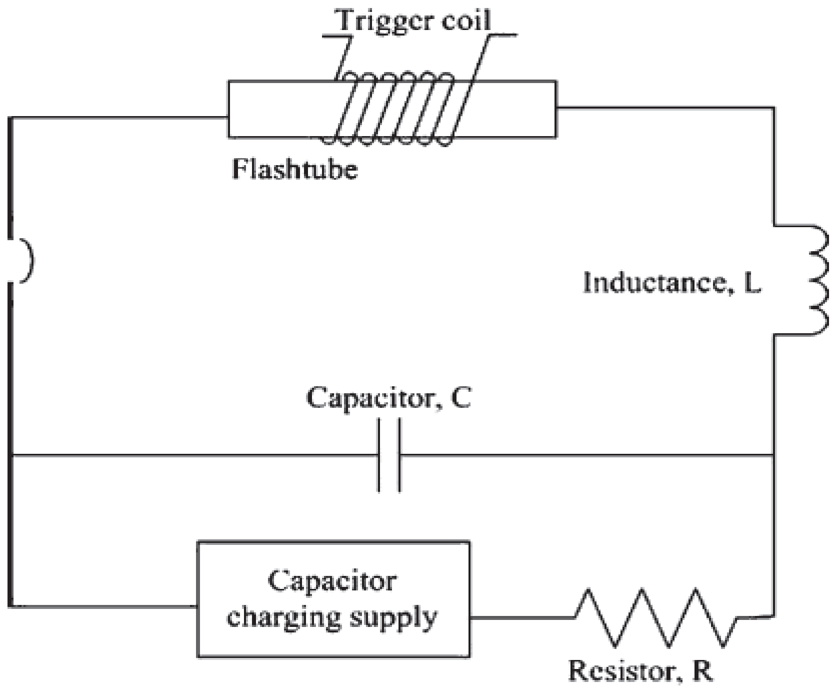

Fig. 2.13 Typical circuitry for the operation of flash lamp

In general, population inversion is achieved by optical pumping and electrical pumping.

In optical pumping, gas-filled flash lamps are most popular. Flash lamps are essentially glass or quartz tubes filled with gases such as xenon and krypton. Some wavelength of the flash (emission spectrum of flash lamp) matches with the absorption characteristics of the active laser medium facilitating population inversion.

This is used in solid-state lasers like ruby and Nd:YAG (yttrium–aluminum–garnet). Typical circuit for the flash lamp operation is shown in Fig. 2.13. Recently, significant interests have been focused towards using diode lasers of suitable wavelength for pumping the solid state lasers. This led to the development of diode-pumped solid-state lasers (DPSS).

The use of diode lasers offers significant advantages over conventional flash lamps such as better match between the output spectrum of the pumping laser and absorption characteristic of laser medium, increased efficiency, and compact and lighter systems. Electrical pumping, used in gas lasers, is achieved by passing a high-voltage electric current directly through the mixture of active gas medium.

The collision of discharge electrons of sufficient kinetic energy excites one of the gases to high energy levels, which subsequently transfer its excitation energy to the second gas through collision, achieving the population inversion. There is minimum population inversion, referred to as threshold condition, required for lasing action [6].

B. Stimulated Emission:

Stimulated emission results when the incoming photon of frequency ν, such that hn = (E2−E1)/h, interacts with the excited atom of active laser medium with population inversion between the states 1 and 2 with energies E1 and E2, respectively. Thus, the incoming photon (stimulating photon) triggers the emission of radiation by bringing the atom to the lower energy state (Fig. 2.14). The resulting radiations have the same frequency, direction of travel, and phase as that of the incoming photon, giving rise to a stream of photons [9].

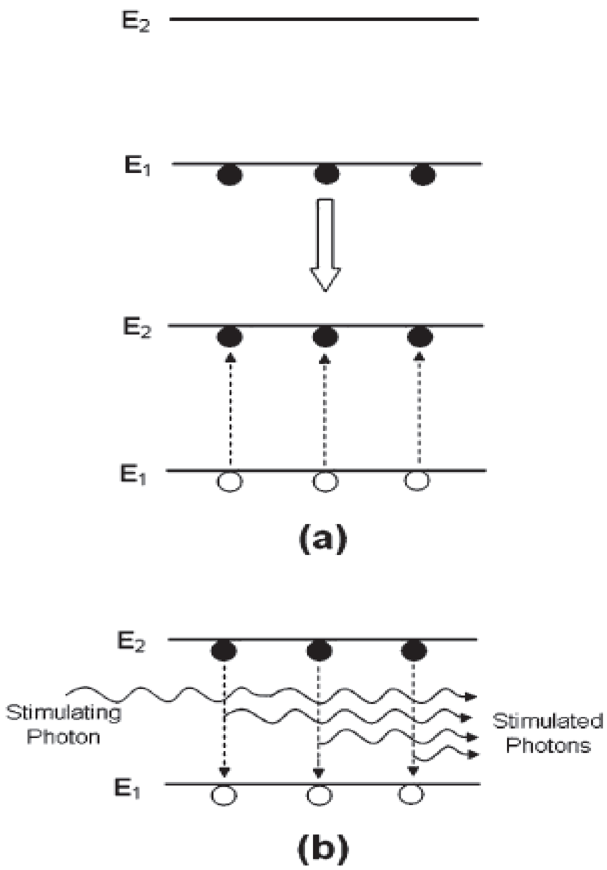

Fig. 2.14 Schematic diagram of laser operation (a) pumping and (b) stimulated emission

C. Amplification:

Since the stimulated photons are in the same phase and state of polarization, they add constructively to the incoming photon resulting in an increase in its amplitude. Thus, the amplification of the light can be achieved by stimulated emission of radiation.

Amplification of laser light is accomplished in a resonant cavity consisting of a set of well-aligned highly reflecting mirrors at the ends, perpendicular to the cavity axis. The active laser material is placed in between the mirrors. Usually, one of the mirrors is fully reflective with reflectivity close to 100%, whereas the other mirror has some transmission to allow the laser output to emerge [10].

Figure 2.15 presents the schematic of the amplification process in the resonator with flat mirrors at the ends and the active laser material in between the mirrors.

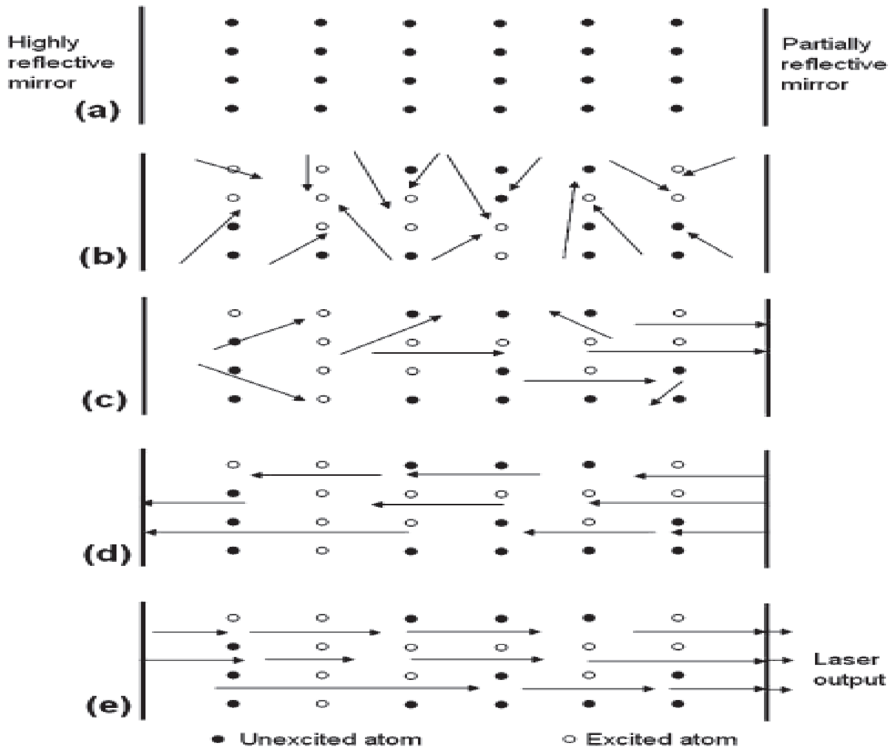

Fig. 2.15 Schematic of amplification stages during operation: (a) initial unexcited state (laser off), (b) optical pumping resulting in excited state, (c) initiation of stimulated emission, (d) amplification by stimulated emission, and (e) continued amplification due to repeated reflection from the end mirrors resulting in subsequent laser output from one end of the mirror

When the laser is off, the optical cavity contains all the laser material in its initial un excited state (Fig.2.15a). The excitation of the atoms (population inversion) is soon achieved by optical pumping (Fig. 2.15b), followed by initiation of stimulated emission (Fig. 2.15c). The intensity of the stimulated radiation is increased as it travels to the end of the mirrors.

Further amplification is accomplished by reflecting the photons into the active medium (Fig. 2.15d). The photons travel the long path back and forth through the lasing medium stimulating more and more emissions resulting in a high-intensity laser beam output from one of the mirrors (Fig. 2.15e).

The preceding discussion on the amplification of stimulated emission assumed that the mirrors of the resonant cavity are flat (plane parallel). However, there are various other configurations which offer significant advantages over the flat mirrors.

Various possible configurations of the resonant cavity mirrors are presented in Fig. 2.16. The important considerations during the designing of the mirrors are the extent of mode volume and the stability of the cavity.

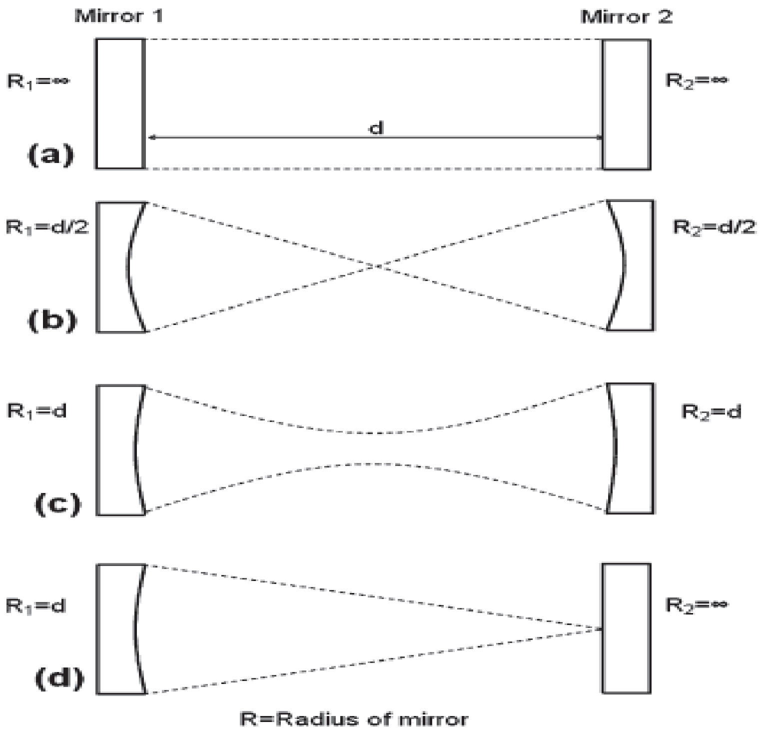

Fig. 2.16 Various mirror configurations for resonant cavities: (a) plane-parallel, (b) spherical, (c) confocal, and (d) hemispherical

The mode volume can be defined as the fraction of the excited laser medium with which the light interacts while oscillating to and fro in the resonant cavity. The extent of mode volume is indicated by the area enclosed by the dashed lines in Fig. 2.16. The stability of the cavity is related with the ability to retain the light rays within the cavity after several reflections between the mirrors.

The plane parallel mirrors have the maximum mode volume. However, slight misalignment may cause the light rays to move off the mirrors after few reflections. Thus, the plane parallel mirrors have high mode volume but relatively low stability. Several combinations of spherical mirrors offer very good stability. However, spherical mirrors are associated with small mode volumes.

2.4.3 Properties of Laser Radiation:

The laser light is characterized by a number of interesting properties. Various applications of lasers exploit specific combinations of the laser properties. This section briefly explains the most important properties of laser light.

i. Monochromaticity:

Monochromaticity is the most important property of laser beam and is measured in terms of spectral line width. The laser output consists of very closely spaced, discrete, and narrow spectral lines, which satisfies the resonance condition given by:

$$d = \frac{n\lambda}{2}, \qquad (4)$$

where d is the cavity length, n is an integer, and λ is the wavelength. These discrete lines, called laser modes or cavity modes, spread over a range of frequencies separated by c/2d, where, c is speed of light (Fig. 2.17) [6].

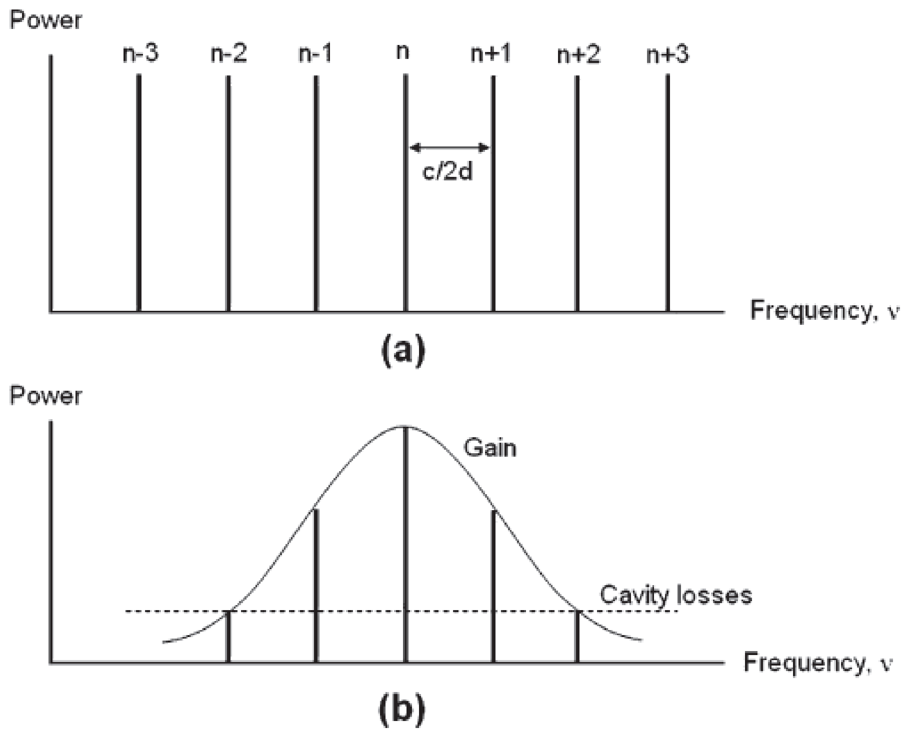

Fig. 2.17 Frequency spectrum in laser output: (a) laser cavity modes, and (b) axial modes in laser output

ii. Collimation:

Collimation of the laser radiation is related with the directional nature of the beam. Highly directional beams are said be highly collimated beams, which can be focused on a very small area even at longer distances. Hence, energy can be efficiently collected on a small area without much loss in the beam intensity. The degree of collimation is directly related with the beam divergence angles.

The beam divergence angles for most of the lasers (except semiconductor lasers) range from 0.2 to 10 milli radians. Collimation of the laser radiation can be improved by using additional optics such as reverse telescope (Fig. 2.18). With the eyepiece and objective lenses of focal lengths f_1 and f_2, respectively, the beam divergence is decreased by the factor f_1/f_2 and the beam width is enlarged by the factor f_2/f_1.

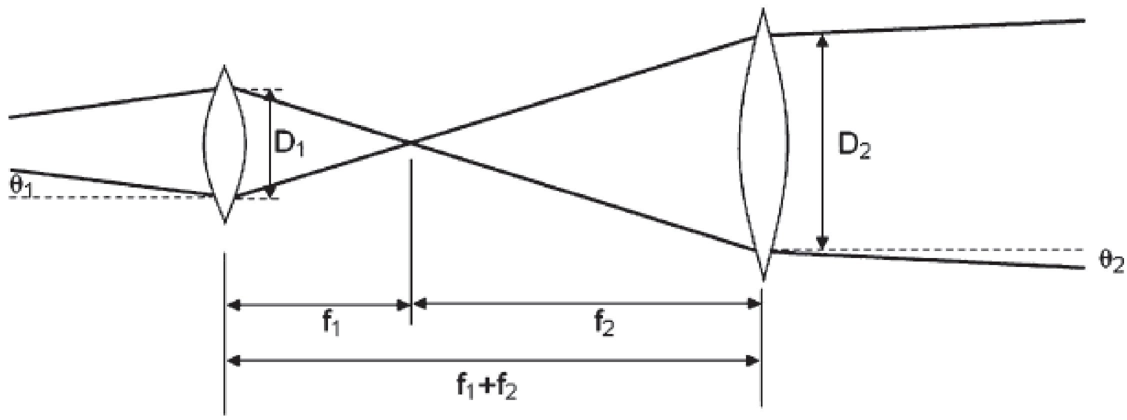

Fig. 2.18 Reverse telescope arrangement for improving the collimation (reducing the divergence) of the beam

Which θ is divergence angles

iii. Beam Coherence:

Coherence is the degree of orderliness of waves and is specified in terms of mutual coherence function, $\gamma_{12}(\tau)$, which is a measure of the correlation between the light wave at two points P1 and P2 at different times t and t + τ The absolute value of $\gamma_{12}(\tau)$ lies between 0 and 1, corresponding to completely incoherent beam and coherent beam, respectively. The two components of beam coherence are spatial and temporal coherence [9].

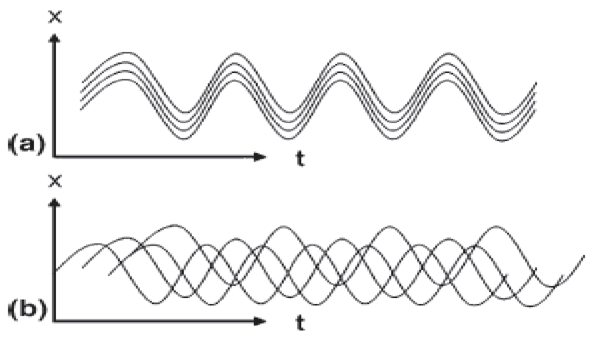

Fig. 2.19 Schematic illustrating the concept of coherence: (a) spatially and temporally coherent light, and (b) spatially and temporally incoherent light

Spatial coherence correlates the phases at different points in space at a single moment in time, whereas temporal coherence correlates the phases at a single point in space over a period of time. Figure 2.19 illustrates the concept of temporal and spatial coherence.

The two important quantities related to temporal coherence are coherence time and coherence length. Coherence properties can be improved by operating the laser in a single longitudinal and transverse mode. Coherence of laser beam is of particular interest in the applications such as interferometry and holography [6].

iv. Brightness or Radiance:

Brightness or radiance is defined as the amount of power emitted per unit area per unit solid angle. Laser beams are emitted into very small divergence angles in the range of 10^{-6} steradians, hence it can be focused on a very small area ensuring the correspondingly high brightness of laser beams.

Brightness of the laser beam is a very important factor in materials processing and determines the intensity (power density) or fluence (energy density) of the laser beam. The brightness of the source cannot be increased by the optical system; however, high brightness characteristics are influenced by operating the lasers in Gaussian mode with minimum divergence angle and high output power [8].

v. Focal Spot Size:

The spot radius is the distance from the axis of the beam to the point at which the intensity drops to $1/e^2$ from its value at the center of the beam. Focal spot size determines the irradiance, which is of prime importance in materials processing; for example, the dominant mechanism of material removal during laser machining such as surface melting or evaporation and the consequent rate of material removal directly depends on the irradiance at the surface. The maximum irradiance corresponds to the minimum diameter of spot. However, it is not possible to focus the beam to an infinitesimal point and there is always a minimum spot size determined by diffraction limit [6].

vi. Transverse Modes:

The cross sections of laser beams exhibit certain distinct spatial profiles termed as transverse modes and are represented as the transverse electromagnetic mode, TEMmn, where m and n are small integers representing the number of nodes in direction orthogonal to the direction of propagation of beam [6].

The various transverse modes are shown in Fig. 2.20. The fundamental mode TEM00 has Gaussian spatial distribution and is the most commonly used mode in laser machining applications.

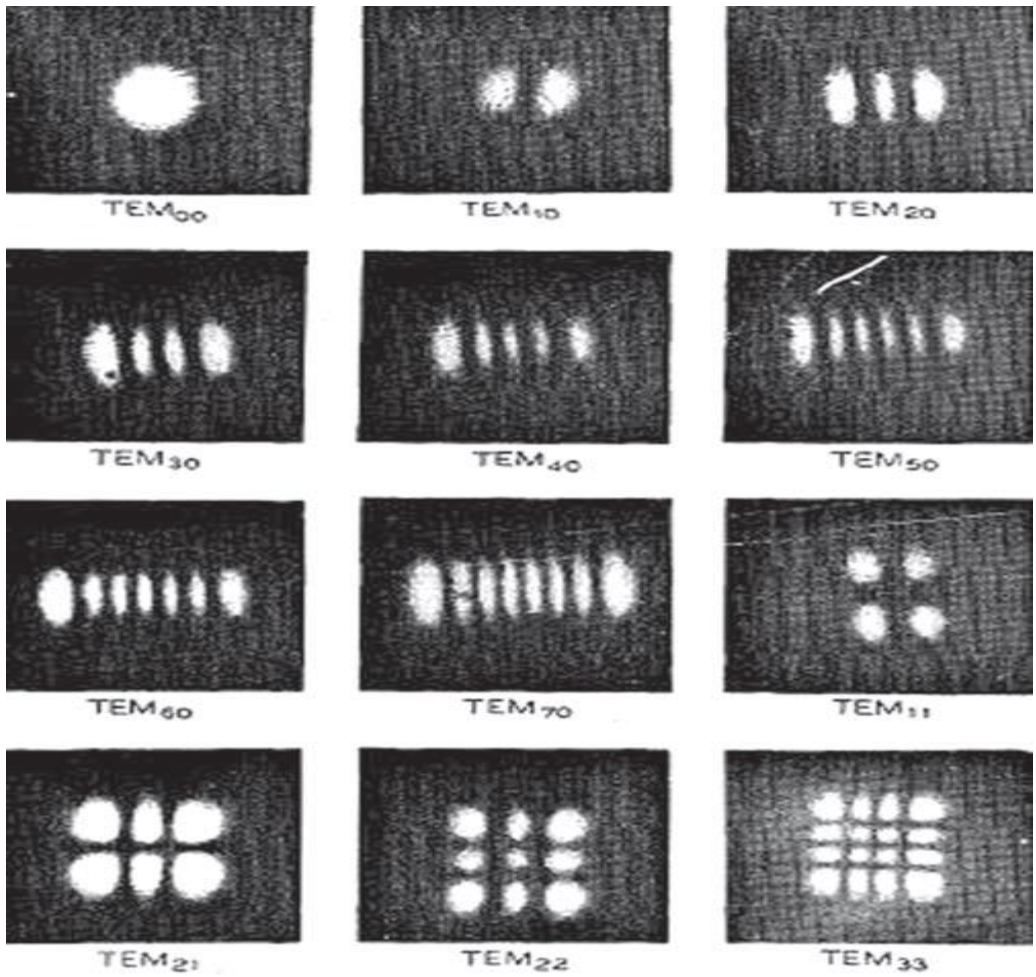

Fig. 2.20 Spatial modes of laser operation.

vii. Temporal Modes:

The output of laser can either be continuous, constant amplitude, known as continuous wave (CW) mode, or periodic, known as pulsed beam mode (Fig. 2.21). In continuous beam operation, constant laser energy is discharged uninterruptedly for a long time. In pulsed mode of operation, the pumped energy is stored until a threshold is reached.

Once the threshold is reached, the stored energy is rapidly discharged into short duration pulses of high energy density. In general, most of the gas lasers and some of the solid-state lasers (Nd:YAG, dye, semiconductor laser) are operated in continuous mode. Solid-state lasers such as ruby Nd:glass lasers are primarily operated in pulsed mode.

One of the important parameters in the pulsed laser operation is the pulse repetition rate. Pulse repetition rate is defined as the number of pulses emitted per unit time. For pulsed lasers the pulsing may be carried out in various ways: normal pulsing, Q-switching, and mode locking [8].

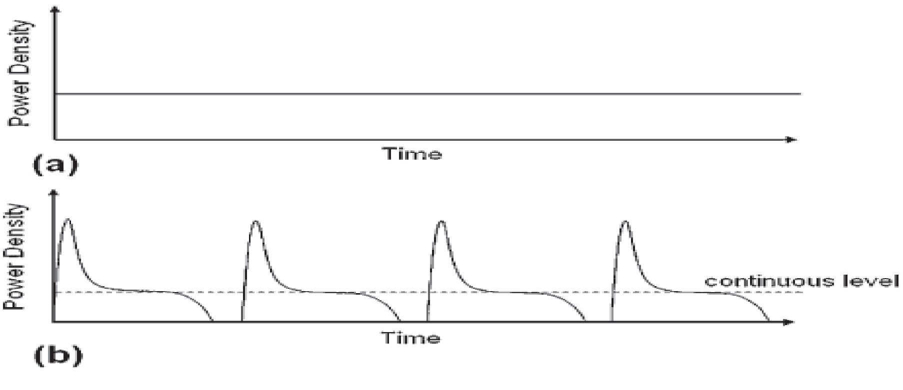

Fig. 2.21 Temporal modes of laser operation: (a) continuous wave mode, and (b) pulsed mode.

a. Normal Pulsing:

In normal pulse operation, the laser pulse duration is primarily controlled by changing parameters of the flash lamp. This is generally achieved by varying the inductance and the capacitance in the circuitry of the flash lamp. No intentional attempts are made to change the properties of the resonator during normal pulsed operation and the laser output is allowed to emerge at its natural rate.

The typical pulse durations for the normal pulses are of the order of microseconds to milliseconds. The typical shape of the normal pulse is shown in Fig. 2.21b. As indicated in the figure, each pulse is characterized by an initial spike with peak power around two or three times the average power during the pulse. After this initial spike, the power drops down.

The pulse (laser output) shown in Fig. 2.21b is approximated by a smooth curve. In actual practice, the normal pulse shape may exhibit the complex shape characterized by spikes of microsecond duration (Fig. 2.22). These microsecond spikes with non uniform amplitude and spacing are often referred to as relaxation oscillations [8].

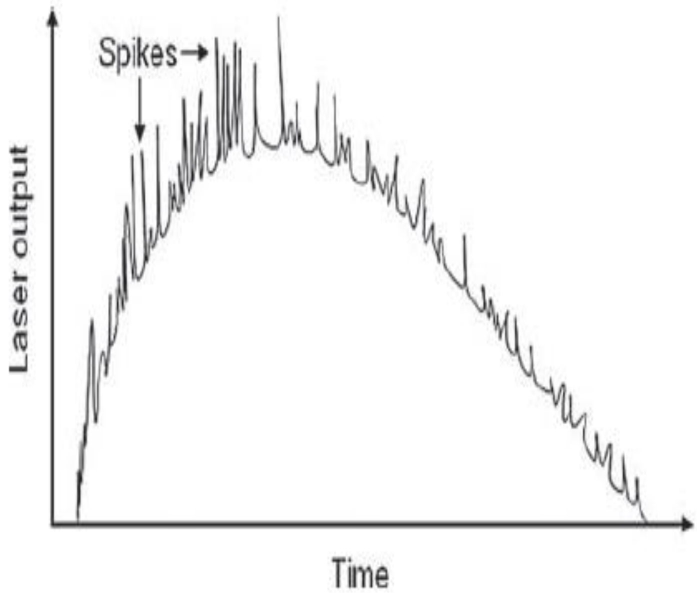

Fig. 2.22 Shape of the normal pulse with a number of spikes of non uniform amplitudes and durations (typically in the range of microseconds)

b. Q-Switching:

The properties of the output laser pulse can be modified by changing the properties of the resonant cavity. In Q-switching, short and intense pulse of laser radiation is obtained by changing the Q value of the cavity. Q value of the cavity is the measure of ability of the cavity to store the radiant energy.

When the Q value is high, energy will be efficiently stored in the cavity without significant laser radiation. If the Q value of the cavity is lowered, the stored energy will emerge as short and intense pulse of laser beam.

Thus, Q-switching involves the “switching” of Q values of the resonant cavity leading to the emergence of short and intense pulse (high peak power) of laser radiation. Various methods of Q switching are: rotating mirror method, electro-optic Q-switching, acousto-optic Q-switching, and passive Q-switching. Pulse repetition rates as high as a few hundred kilo hertz can be obtained in Q-switched laser operation [8].

c. Mode Locking:

As explained in Section 2.3.3.7.B, Q-switching produces short and intense pulse after each pumping pulse in the laser output. In mode locking operation, a train of extremely short and equally spaced pulses is produced (Fig. 2.23).

The mode locking is due to interaction between the longitudinal modes and results in oscillatory behavior of the laser output. It can be achieved by modulating the loss or gain of the laser cavity at a frequency equal to the inter mode frequency separation ($\Delta n = c/2d$). This makes the longitudinal modes maintain fixed phase relationship resulting in mode locking. Typical pulse repetition rates in mode-locked laser operation are in the range of megahertz to gigahertz [8].

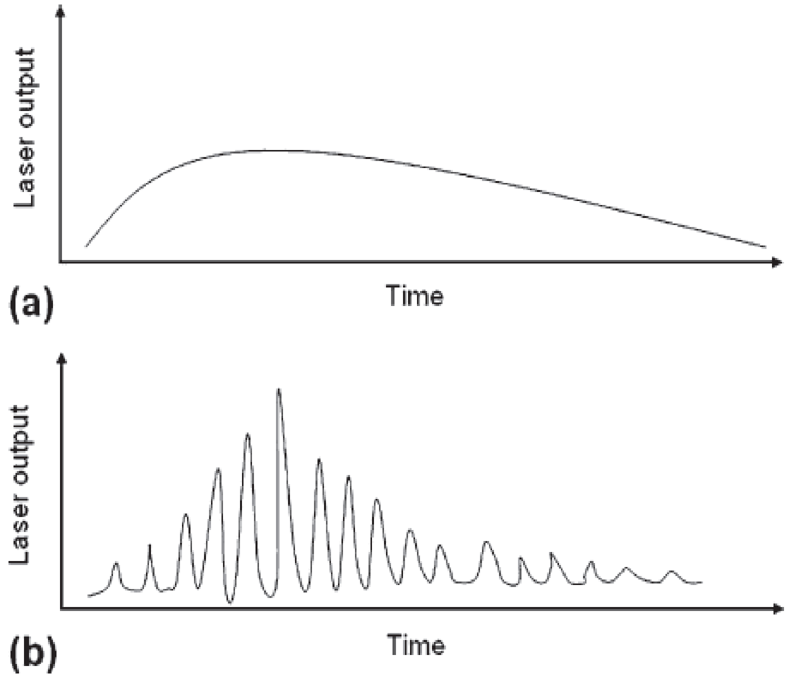

Fig. 2.23 Schematic of the pulse characteristic in the (a) Q-switched laser operation and (b) Q-switched with mode locking operation

viii. Frequency Multiplication:

The frequency of the laser beam can be multiplied by using frequency multiplier materials. The frequency multiplier materials are characterized by the beam's nonlinear response to the electric field. The frequency of the laser radiation can be doubled (second harmonic generation) or tripled (third harmonic generation) without adversely affecting the basic properties of laser radiation. Common frequency multiplier materials include potassium dihydrogen phosphate (KDP), and lithium niobate [6].

2.4.4 Types of Industrial Lasers:

Since the development of the first ruby laser in 1960, the laser action has been demonstrated in hundreds of materials. However, the range and variety of active materials for commercial lasers are still limited. Lasers are generally classified into four main types depending on the physical nature of the active medium used: solid-state lasers, gas lasers, semiconductor lasers, and dye lasers. Table 2.1 gives the list of important lasers in each category.

Table 2.1 Typical wavelengths of various types of lasers

Laser type	Wavelength (nm)
Solid-state lasers	
Nd:YAG	1,064
Ruby	694
Nd:glass	1,062
Alexandrite	700–820
Ti-sapphire	700–1,100
Er:YAG	2,940
Nd:YLF	1,047
Gas lasers	
HeNe	632.8
Argon	488, 514.5
Krypton	520–676
HeCd	441.5, 325
CO_2	10,600
ArF	191
KrF	249
XeCl	308
XeF	351
Copper vapor	510.6, 578.2
Gold vapor	628
Semiconductor lasers	
InGaAs	980
AlGaInP	630–680
InGaAsP	1,150–1,650
AlGaAs	780–880
Liquid dye lasers	
Rhodamine 6G	570–640
Coumarin 102	460–515
Stilbene	403–428

A. Solid State Lasers:

In solid-state lasers, active medium consists of a small percentage of impurity ions doped in a solid host material. The first practical solid-state laser was the ruby laser developed by Maimam in 1960. Large numbers of lasers such as Nd:YAG, Nd: glass, alexandrite, and Ti:sapphire are now available in this class. Among these, Nd:YAG laser is the most commonly used one in the laser machining applications. Hence, operating principles of Nd:YAG laser are explained here[6].

i. Nd:YAG Laser:

Nd:YAG laser consists of crystalline yttrium aluminium garnet (YAG) with a chemical formula $Y_3Al_5O_{12}$ as a host material. The triply ionized neodymium (Nd^{3+}) ions substitute yttrium ion sites in the lattice with a maximum doping level of around 2%. This is a typical four-level energy laser system earlier illustrated in Fig. 2.12b. Such systems offer significant advantages such as ease of achieving population inversions. Hence, simple designs of flash lamps with modest amount of pumping energy are sufficient to achieve the efficient population inversions.

The energy levels involved in the population inversion and the laser transitions are shown in Fig. 2.24. Laser transitions takes place between the $^4F_{3/2}$ level and the $^4I_{11/2}$ level. Due to splitting of initial and final energy levels, several lasing wavelengths are possible, 1.064 μm being the strongest one.

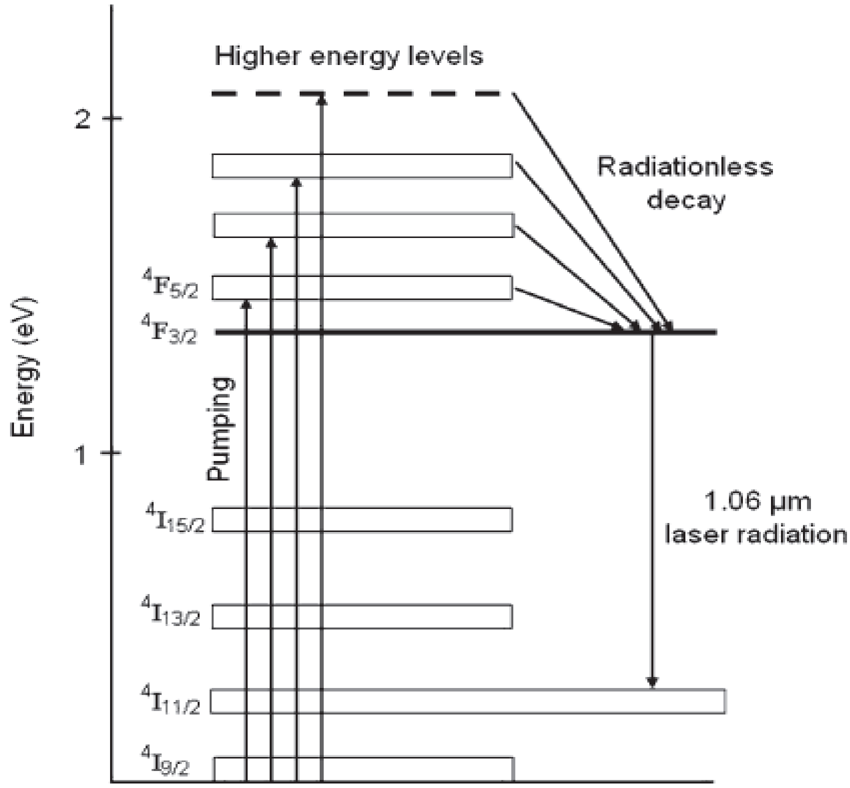

Fig. 2.24 Schematic of the energy levels of neodymium ion showing the levels involved in population inversion (pumping) and laser transitions

The output of the Nd:YAG laser can be continuous, pulsed, or Q-switched. The light source for pumping depends on the absorption characteristics of the crystal. For continuous operation the laser is excited by continuous krypton-filled or xenon-filled arc lamps or semiconductor diode lasers [6].

Krypton lamps are efficient pumping sources for continuous Nd:YAG laser because the emission lines from Krypton lamps agrees better with absorption lines in Nd:YAG. For pulsed operation, flash lamps are generally used.

If the pulses of relatively large-pulse energy are desired, the laser is excited by a flash lamp, which gives pulses at relatively low pulse repetition rates. Nd:YAG laser is also available in frequency-doubled mode in which the output of the laser is in the green portion of the visible spectrum at 532 nm. In addition to frequency doubled operation, the laser is also available in frequency-tripled (355 nm) and frequency-quadrupled (266 nm) modes [6].

B. Gas Lasers:

In gas lasers, as the name suggests, the active laser medium is gas. Gaseous laser materials offer significant advantages over solid material. Some of these advantages are:

1. Gases acts as homogeneous laser medium.
2. Gases can be easily transported for cooling and replenishment.
3. Gases are relatively inexpensive.

However, due to physical nature of the gases (low densities), a large volume of gas is required to achieve the significant population inversion for laser action. Hence, gas lasers are usually relatively larger than the solid-state lasers. Gas lasers can be classified into atomic, ionic, and molecular lasers depending on whether the laser transitions are taking place between the energy levels of atoms, ions, and molecules, respectively. There are several laser systems in each class. Only CO_2 gas lasers are explained in this section [6].

ii. **CO_2 Laser:**

CO_2 laser is one of the most important lasers in the laser machining of materials. This is a molecular gas laser consisting of CO_2 gas as its active medium. The CO_2 molecule can undergo three different types of vibrations such as symmetric stretching, bending, and asymmetric stretching (Fig. 2.25). Energy associated with these vibrational modes is quantized [10].

In addition to the symmetric and asymmetric vibrations, the molecule can also rotate. However, the energy associated with the rotational modes is much smaller than the vibrational modes.

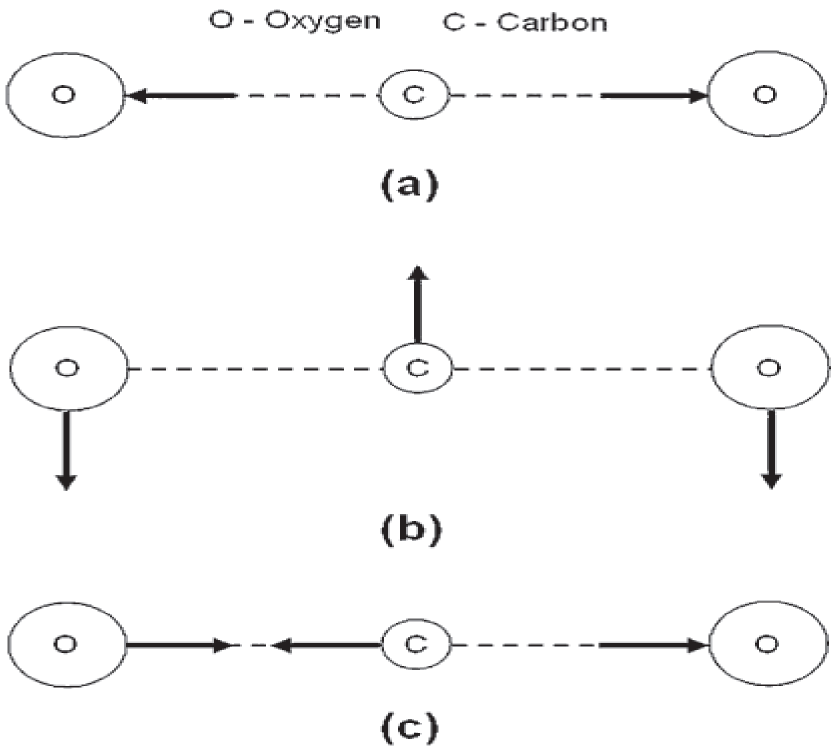

Fig. 2.25 Vibrational modes the CO_2 molecule: (a) symmetric stretching, (b) bending, and (c) asymmetric stretching

This results in the splitting of vibrational energy levels into a number of closely spaced rotational sublevels. The excited state of the CO_2 molecule corresponds to the presence of one or more quanta of energy. The energy level diagram for the operation of CO_2 laser is presented in Fig. 2.26. The operation begins with vibrational excitation of the nitrogen molecules by electrical discharge.

As indicated in the figure, the vibrational excitation of the nitrogen molecule closely corresponds to the (001) vibrational levels of CO2. The excited vibrational levels of nitrogen are metastable. The nitrogen molecule exchanges collisional energy with the CO2, resulting in vibrational excitation of CO2 molecules.

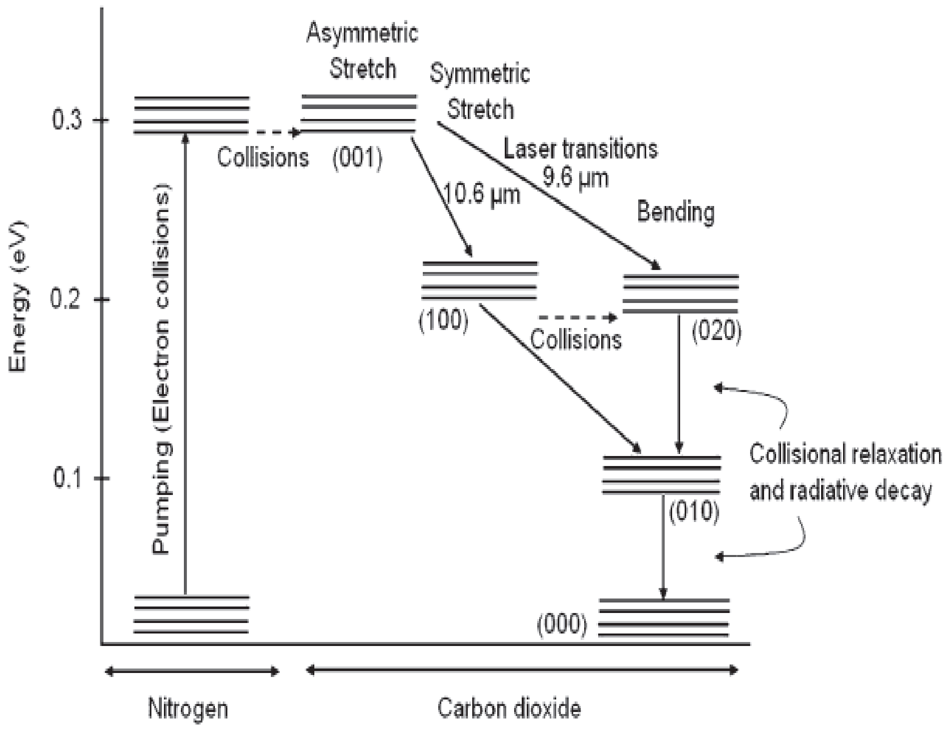

Fig. 2.26 Schematic of the energy levels involved in the operation of CO2 laser

Laser transition takes place between initial level (001) and final levels (100) and (020), resulting in 10.6 and 9.6 μm laser radiations, respectively.

However, the laser radiation at 10.6 μm is the strongest and forms the most usual mode of operation. The practical CO_2 lasers use a mixture of CO_2, nitrogen and helium. The addition of helium increases the output power. The properties of a CO_2 laser are mainly determined by the method of gas flow in which sealed discharge tube, axial flow, and transverse or cross flow are primarily used. CO_2 lasers can be operated in both continuous and pulsed modes [6].

C. Semiconductor Lasers:

Semiconductor lasers, as the name suggests, use semiconductor materials as active medium. Even though it appears at first sight that semiconductor lasers are solid state lasers, actually they are significantly different. Semiconductor lasers are based on radiative recombination of charge carriers. To understand the operation principles of semiconductor lasers it is necessary to understand the energy band structure of semiconductors.

Typical energy band diagrams of the p–n junction in open circuit, forward bias, and reverse bias are shown in Fig. 2.27. When a p-type semiconductor is brought in contact with the n-type semiconductor at a junction, the electrons from the n-type region diffuse toward the p-type region. Similarly, holes from the p-type region diffuse toward the n-type region.

The diffusive flow of charge carriers (electrons and holes) in opposite directions results in the charge separation on the two sides of the junction.

The charge separation and the consequent electric field oppose the further diffusion of charge carriers. At equilibrium, an electron in the n-type region must overcome the built-in potential (eV_0) to diffuse into the p-type region (open circuit). When external potential (V) is applied such that the p-type region is made negative and the n-type region is made positive, the external potential adds to the built-in potential resulting in increased potential barrier, $e(V_0 + V)$. Hence, the diffusion of electrons from the n-type region to the p-type region becomes increasingly difficult (reverse bias).

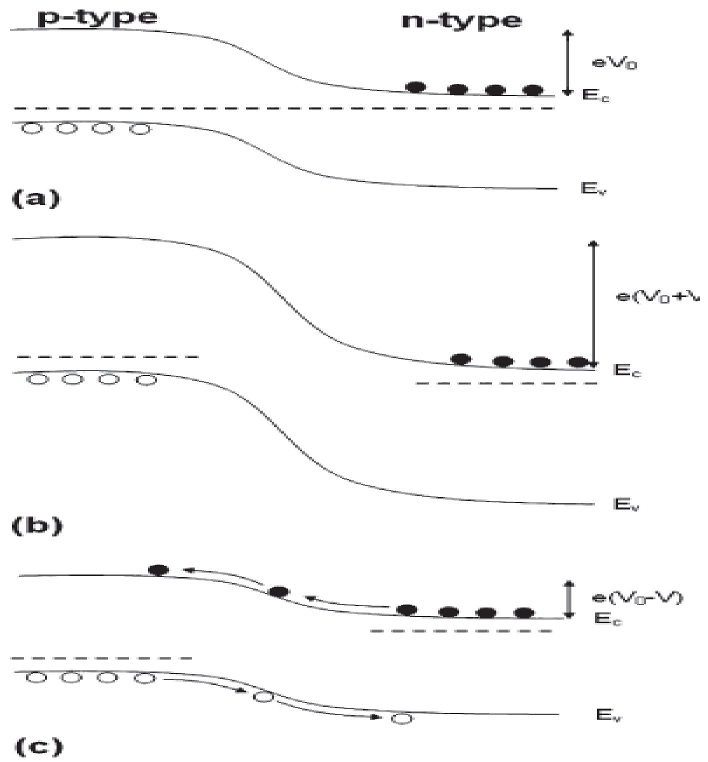

Fig. 2.27 Energy band diagrams for a p–n junction: (a) open circuit, (b) reverse bias, and (c) forward bias

However, when the external potential (V) is applied such that the p-type region is made positive and the n-type region is made negative, it reduces the potential barrier from eV_0 to $e(V_0 - V)$. The electrons now face the reduced potential barrier, which they can easily overcome while diffusing from the n-type region to the p-type region. Similarly, holes can diffuse from the p-type region to the n-type region (forward bias).

The battery in the circuit can replenish the charges and establish the current flow through the junction. The electrons and holes injected into the p-type and n-type regions, respectively, act as minority charge carriers and undergo recombination (Fig. 2.28).

The recombination of minority charge carriers results in the spontaneous emission of photons. This is the basic principle of light emitting diodes (LEDs). Under certain circumstances, lasing action can occur [6].

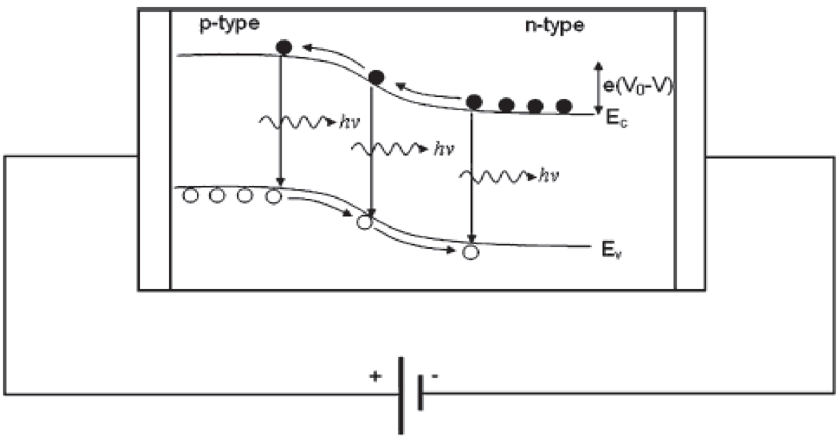

Fig. 2.28 Recombination of minority charge carriers resulting in emission of photons (forward bias)

Laser action in gallium arsenide (GaAs) and Gallium arsenide phosphide (GaAsP) laser diodes at cryogenic temperature was demonstrated as early as 1962 . The application of diode laser in that period was limited by the poor output power. However, these semiconductor lasers are now becoming increasingly popular both as a pump source for solid-state laser and in materials processing because of their unique features like small size, low weight‘ high efficiency, and reliability.

Diode lasers have a potential scope of application in materials processing and gaining increasing popularity because of its lower installation/ maintenance cost and greater efficiency over CO2 and Nd:YAG lasers [11].

D. **Liquid Dye Lasers**:

Liquid dye lasers consist of liquid solutions (organic dyes dissolved in suitable liquid solvents) as active laser materials. Due to the physical nature (low density, homogeneity, etc.) of the liquid media, the liquid dye lasers are relatively easy to fabricate and are associated with advantages such as ease of cooling and replenishment in the laser cavity.

One of the most important characteristics of the dye lasers is the tunability over the wide range of wavelengths (0.2–1.0 μm). This comes from the spectral properties of the organic dye molecules. The dye molecules efficiently absorb radiation over a certain range of wavelength and re-emit over other broad bands at longer wavelengths.

This is illustrated for typical dye material, rhodamine 6G, in Fig. 2.29 A. A generalized energy level diagram for the dye molecule is presented in Fig. 2.29B. As indicated in the figure, pumping causes the transitions $S_0 \rightarrow S_1$ and $S_0 \rightarrow S_1$. The molecule then rapidly (time $\sim 10^{-11}$ s) relaxes to the lowest levels of the S1 band. The laser radiations are due to transitions $S_1 \rightarrow S_0$. Since the transitions take place between the bands of energy levels, laser radiations over a wide range of wavelengths are possible.

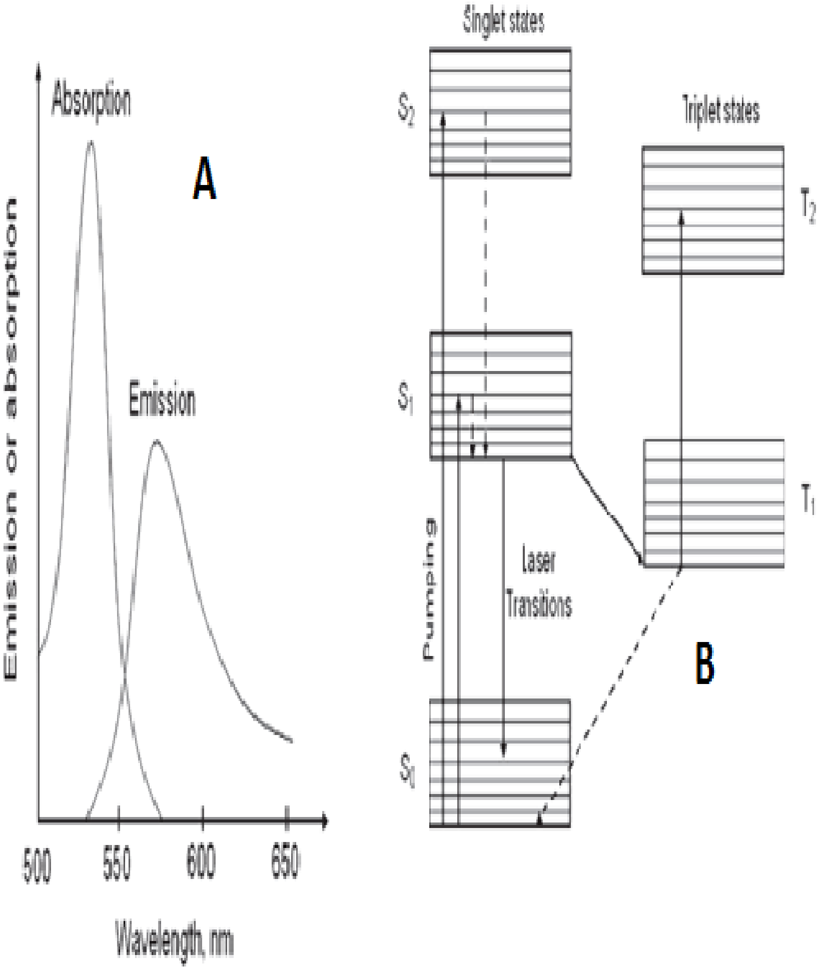

Fig. 2.29 A - Schematic of the spectral characteristics of rhodamine 6G B-Energy level diagram for dye molecule

Thus, the tunability of the laser over a wide range of wavelengths is an important characteristic of dye lasers. The operation of dye lasers is also associated with undesirable transitions such as S1→T1. This transition represents the loss and lowers the laser efficiency. For better laser efficiency, S1→S0 transitions should be maximized and S1→T1 transitions should be minimized. A variety of dye materials is available with a wide tuning range of wavelengths [6].

2.4.5. **Laser Drilling**:

Laser drilling is one of the earliest applications of lasers in materials processing. Output energies of the first ruby laser were often described in terms of the number of razor blades which could be penetrated by the focused laser beam. Laser drilling is most extensively used in the aerospace, aircraft, and automotive industries.

The most important application of laser drilling in the aerospace industry is the drilling of a large number of closely spaced effusion holes with small diameter and high quality to improve the cooling capacity of turbine engine components. In addition, laser drilling of diamond drawing dies and gemstones have been extensively used. The common industrial applications of laser drilling include cooling holes in aircraft turbine blades, optical apertures, flow orifices, and apertures for electron beam instruments.

Laser drilling is a noncontact, precise, and reproducible technique that can be used to form small diameter (~100μm) and high aspect ratio holes in a wide variety of materials. The advantages of laser drilling include the ability to drill holes in difficult to machine materials such as super alloys, ceramics, and composites without high tool wear rate normally associated with conventional machining of these materials.

Conventional mechanical drilling is often a slow process (drilling time ~60 s/hole) and associated with difficulties of drilling a thigh angles. Drilling rates as high as 100 holes/s can be achieved in production environment by coordinating the workpiece motions with pulse period of pulsed laser source. Laser drilling does not pose substantial problems at high angles of incidences.

Laser drilling is also well suited for the non conducting substrates or metallic substrates coated with non conducting materials where the electric discharge machining is limited. For example, the drilling of thermal barrier coated super alloys in aerospace applications can be well achieved by laser drilling instead of electrical discharge machining.

In addition, recently the laser drilling of composite materials such as multilayer carbon fiber composites for aircraft applications is attracting increasing interest due to potential advantages of rapid processing, absence of tool wear, and ability to drill high-aspect ratio holes at shallow angles to the surface [3].

Table 2.2 compares laser drilling with its major competing processes, namely mechanical drilling and EDM drilling [10].

Process	Advantages	Disadvantages
Mechanical Drilling	Matured process for large and deep hole drilling, high material removal rate, low equipment cost, straight holes without taper, accurate control of diameter and depth. Applicable to wider range of materials than EDM but narrower range of materials than laser drilling. Typical aspect ratio 1.5:1.	Drill wear and breakage, low throughput and long setup time, limited range of materials, difficult to drill small holes high aspect ratio holes, difficult for irregular holes.
Electrical Discharge Machining EDM	Large depth and large diameter possible, no taper, low equipment cost, can drill complex holes. Mainly applicable to electrical conductive materials. Typical aspect ratio 20:1.	Limited range of materials, slow drilling rate, need to make tools for each type of hole, setup time; high operating cost
Laser Drilling	High throughput, noncontact process, no drill wear or breakage, low operating cost, easy fixtures and easy automation, high speed for small hole drilling, high accuracy and high consistency in quality, easy manipulation of drilling location and angle, complex geometry possible, high quality and thick depth in drilling of many nonmetal materials. Applicable to a very wide range of materials. Typical aspect ratio 10:1.	Limited depth and not economical for large holes, hole taper and material re deposition for drilling of metals, high equipment cost.

i. Laser Drilling Approaches:

In laser drilling, the high intensity, stationary laser beam is focused onto the surface at power densities sufficient to heat, melt, and subsequently eject the material in both liquid and vapor phases. The erosion front at the bottom of the drilled hole propagates in the direction of the line source in order to remove the material.

In general, there are four approaches to laser drilling, namely, single pulse, trepanning, and percussion drilling and helical drilling. These are shown in Fig. 2.30. A coaxial assist gas is almost always used while drilling in order to shield the laser optics from contamination from ejected debris and also to facilitate the material removal [6].

Single pulse drilling is used for drilling narrow (less than 1 mm) holes through thin (less than 1 mm) plates. High pulse energies are supplied in drilling with single pulse because the irradiated energy levels must be sufficient to vaporize the material in single pulse [6].

An example of single-pulse drilling is found in the automotive industry, where it creates a scribed guideline for breaking off (cracking) a connecting rod for diesel engines. Scribing, in effect, drills blind holes close enough to create a notch. Another single-pulse drilling application in the automotive industry is in manufacturing filters [2].

In trepanning, wider holes (less than 3 mm) in thicker plates (less than 10 mm) are produced by drilling a series of overlapping holes around a circumference of a circle so as to cut a contour out of the plate. Trepanning can be performed by translating either the workpiece or the focusing optic.

The process is much similar to contour cutting and can be performed by the laser operating in the continuous wave (CW) or pulsed mode. CO2 and Nd:YAG lasers are most commonly used in trepanning[6].

In percussion drilling, a series of short pulses (10^{-12} to 10^{-3} s) separated by longer time periods (10^{-2} s) are directed on the same spot to form a through hole. Each laser pulse contributes to the formation of hole by removing a certain volume of material. Pulsed Nd:YAG lasers are most commonly used for percussion drilling because of their higher energy per pulse.

Percussion drilling is used to produce narrow holes (less than 1.3 mm) through relatively thicker (up to 25 mm) metal plates. High speed of the percussion drilling makes it the most cost effective method in applications such as drilling of combustion chambers having 40,000–50,000 holes and other applications such as drilling of turbine and guide vanes having 50–200 holes, given the large number of total components involved.

In helical drilling A new technique, called Helical Drilling, makes use of the breaking up of the process into a multitude of ablation steps in order to enhance the accuracy.

In contrast to trepanning, the helical drilling reaches the breakthrough only after many turns of spiral describing the path of the ablation front. Helical drilling has the following favorable effects on drilling accuracy: more deviation from circular geometry can be reduced than trepanning; the load on the opposite walls is minimized; and most importantly, recast layers as observed in percussion drilling using nanosecond lasers can be greatly reduced [2].

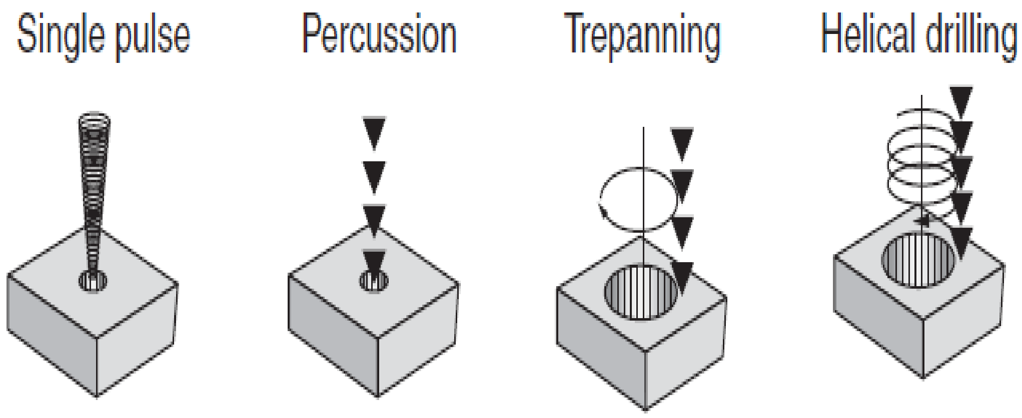

Fig. 2.30 Approaches for laser drilling single pulse drilling, trepanning drilling, and percussion drilling and helical drilling

ii. Laser Drilling Applications:

Laser drilling is currently used in many industrial applications for large scale production. In addition, laser drilling is increasingly replacing conventional drilling techniques for various applications. This section gives an overview of the established applications of laser drilling along with a brief mention of the applications where laser drilling is likely to be a dominant technology.

a. Drilling of Cooling Holes:

Laser drilling of cooling holes in aerospace gas turbine parts such as turbine blades، nozzle guide vanes, combustion chambers, and afterburners is an established technology.

These parts are typically made of nickel-based super alloys which are difficult to machine using conventional techniques. Figure 2.31 shows a laser-drilled component of gas turbine. Such closely spaced cooling holes increase the efficiency of the engines and allow the higher operating temperatures.

The most preferred drilling technique in such applications uses Nd:YAG laser in a trepanning drilling mode. However, other laser sources can also be used in various different laser drilling modes based on the size, depth, and quality of the desired holes.

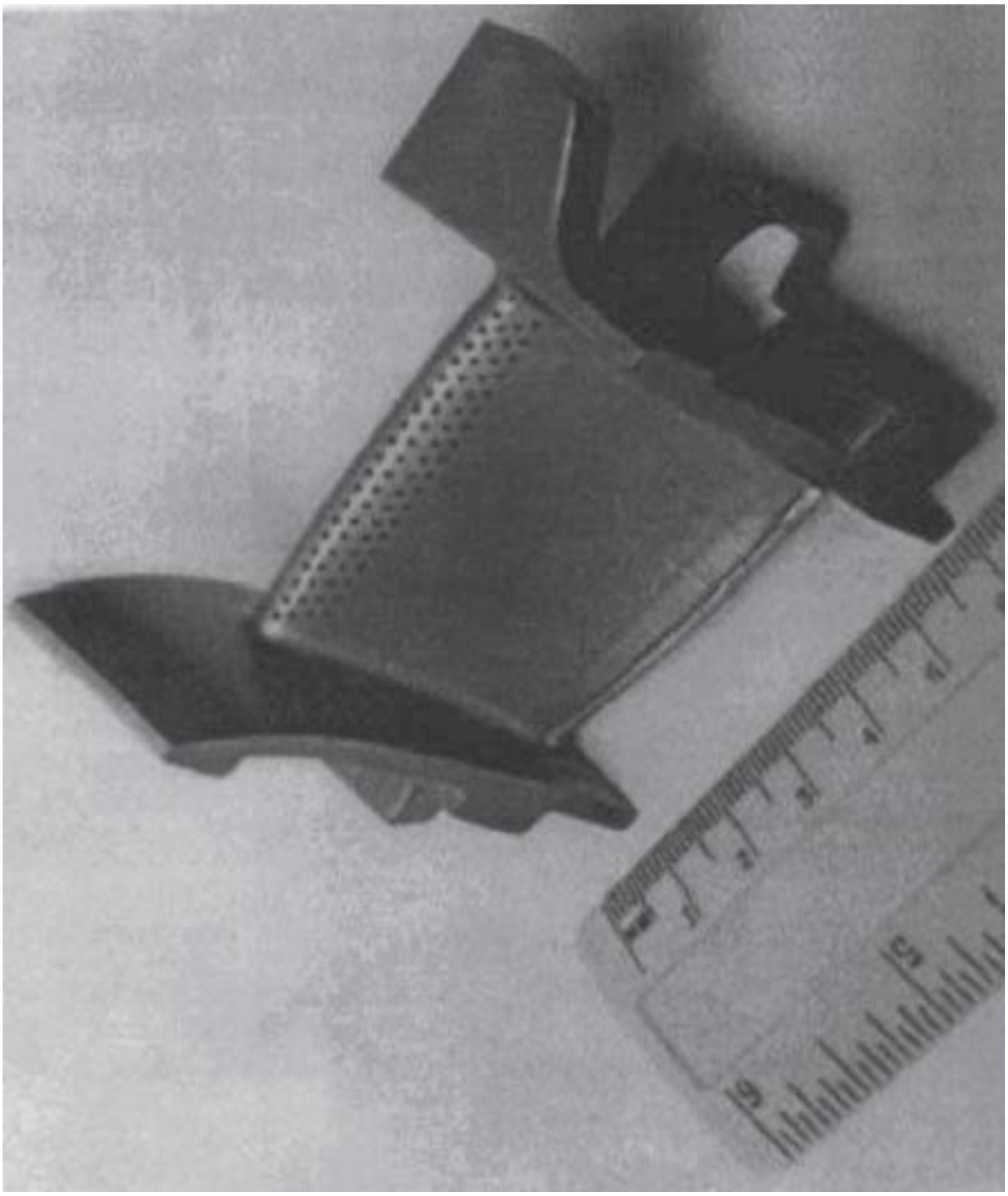

Fig. 2.31 Laser-drilled holes in an aerospace component.

b. Drilling of Diamonds:

Diamonds, being highly transparent and the hardest known material, presents unique difficulties for machining. Drilling of natural and synthetic diamonds is of particular interest for many applications.

Pulsed solid-state lasers are used for drilling diamond wire drawing dies to produce high finish, precisely profiled holes with minimum heat affected zone.

In addition, laser drilling is used in jewelry to enhance the clarity grade of diamonds by helping in removing the trapped inclusions. Lasers are used to bore a small hole in the diamond from the surface to the targeted inclusion, which is subsequently bleached out or burned away by forcing a strong acid through the drilled hole [6].

c. Micro Drilling:

Lasers are now extensively used in the micromachining applications where feature resolution in the range of micron and submicron is required. Many of these micro drilling. One such application is the drilling of holes in the head plate of ink jet printers. Ink jet printer heads consists of an array of tapered holes through which the ink droplets are squirted on the paper. The resolution of the prints can be increased by increasing the number of holes and decreasing the hole diameter and pitch of the holes in the head.

Modern printers use excimer lasers to drill 300 holes of 28 μm diameter compared to earlier printers which used electroforming to produce 100 holes of 50 μm diameter.

In addition to the increased resolution (600 dots per inch), laser drilling gives higher production yields (> 99%) compared to conventional resolution of 300 dots per inch and production yield of 70–85%. [6].

2.5 Stepper Motors :

Stepper motors are electromagnetic incremental devices that convert electric pulses to shaft motion (rotation). These motors rotate a specific number of degrees as a respond to each input electric pulse. Typical types of stepper motors can rotate 2°, 2.5°, 5°, 7.5°, and 15° per input electrical pulse. Rotor position sensors or sensor less feedback based techniques can be used to regulate the output response according to the input reference command [13].

Stepping motors fill a unique niche in the motor control world. These motors are commonly used in measurement and control applications. Sample applications include ink jet printers, CNC machines and volumetric pumps. Several features common to all stepper motors make them ideally suited for these types of applications. These features are as follows:

a. Brushless – Stepper motors are brushless. The commutator and brushes of conventional motors are some of the most failure-prone components, and they create electrical arcs that are undesirable or dangerous in some environments.
b. Load Independent – Stepper motors will turn at a set speed regardless of load as long as the load does not exceed the torque rating for the motor.
c. Open Loop Positioning – Stepper motors move in quantified increments or steps. As long as the motor runs within its torque specification, the position of the shaft is known at all times without the need for a feedback mechanism.

d. Holding Torque – Stepper motors are able to hold the shaft stationary.

d. Excellent response to start-up, stopping and reverse [14].

2.5.1. Stepper Motor Advantages:

i. The rotation angle of the motor is proportional to the input pulse.

ii. B. The motor has full torque at standstill (if the windings are energized)

iii. Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 – 5% of a step and this error is non cumulative from one step to the next.

iv. Excellent response to starting/stopping/reversing.

v. Very reliable since there are no contact brushes in the motor. Therefore, the life of the motor is simply dependent on the life of the bearing.

vi. The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.

vii. G. It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.

viii. H. A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

2.5.2 Stepper Motor Disadvantages:

1. Resonances can occur if not properly controlled.
2. Not easy to operate at extremely high speeds.

2.5.3 Stepper Motor Types:

There are three basic stepper motor types [14]:

A. Variable-reluctance.
B. Permanent-magnet.
C. Hybrid.

A. Variable Reluctance Stepper Motors:

Variable Reluctance Motors (also called variable switched reluctance motors) have three to five windings connected to a common terminal. Figure 2.32 shows the cross section of a three winding, 30 degrees per step variable reluctance motor. The rotor in this motor has four teeth and the stator has six poles, with each winding wrapped around opposing poles.

The rotor teeth marked X are attracted to winding 1 when it is energized. This attraction is caused by the magnetic flux path generated around the coil and the rotor. The rotor experiences a torque and moves the rotor in line with the energized coils, minimizing the flux path. The motor moves clockwise when winding 1 is turned off and winding 2 in energized. The rotor teeth marked Y are attracted to winding 2. This results in 30 degrees of clockwise motion as Y lines up with winding 2.

Continuous clockwise motion is achieved by sequentially energizing and de-energizing windings around the stator. The following control sequence will spin the motor depicted in Figure 2.32 clockwise for 12 steps or one revolution.

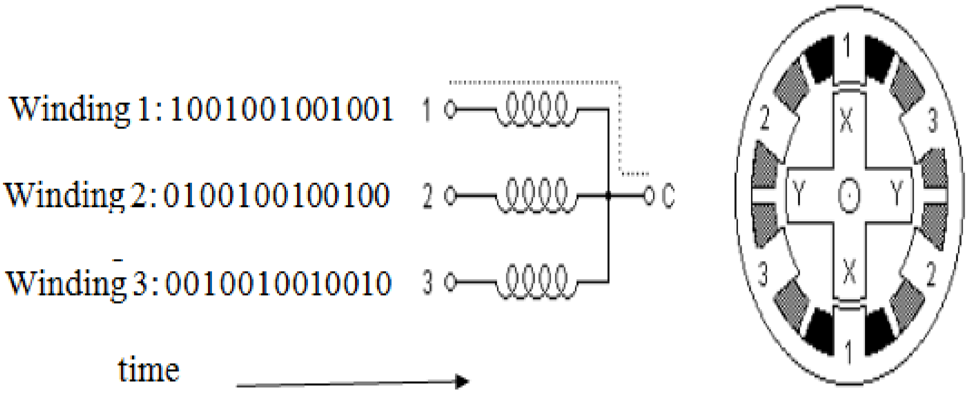

Fig.2.32. Variable Reluctance Stepper Motors

In figure 2.32. illustrates the most basic variable reluctance stepping motor. In practice, these motors typically have more winding poles and teeth for smaller step angles. The number of poles can be made greater by adding windings, for example, moving to 4 or 5 windings, but for small step angles, the usual solution is to use toothed pole pieces working against a toothed rotor. Variable reluctance motors using this approach are available with step angles close to one degree [14].

B. Permanent Magnet Stepper Motors:

Permanent magnet (PM) stepper motors are similar in construction to that of variable reluctance stepper motors except that the rotor is made of permanent magnet.

Permanent magnet stepper motors offer many features compared to variable reluctance type such as:

1) Higher inertia and consequently lower acceleration (deceleration) rates.
2) Maximum step pulse rate is 300 pulses per second compared to 1200 pulses per second for variable reluctance stepper motors.
3) Larger step sizes, ranging from 30° to 90° compared to step sizes as low as 1.8° for variable reluctance stepper motors.
4) Generate higher torque per ampere of stator currents than variable reluctance stepper motors.

C. Hybrid Motors:

Hybrid motors share the operating principles of both permanent magnet and variable reluctance stepping motors. The rotor for a hybrid stepping motor is multi toothed, like the variable reluctance motor, and contains an axially magnetized concentric magnet around its shaft see Figure2.33. The teeth on the rotor provide a path which helps guide the magnetic flux to preferred locations in the air gap. The magnetic concentric magnet increases the detent, holding and dynamic torque characteristics of the motor when compared with both the variable reluctance and permanent magnet types [14].

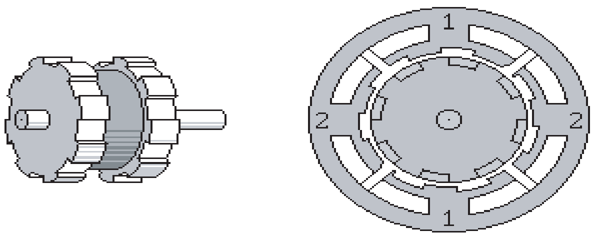

Fig.2.33. Hybrid Stepper Motors

2.5.4 Drive Circuit of Stepper Motors:

There are two main drive circuits for stepper motors, namely; Uni-polar and Bi-polar drive circuits.

i. Unipolar Stepping Motors:

Unipolar stepping motors are composed of two windings, each with a center tap. The center taps are either brought outside the motor as two separate wires as shown in figure 2.34 or connected to each other internally and brought outside the motor as one wire. As a result, unipolar motors have 5 or 6 wires. Regardless of the number of wires, unipolar motors are driven in the same way.

The center tap wire(s) is tied to a power supply and the ends of the coils are alternately grounded. Unipolar stepping motors, like all permanent magnet and hybrid motors, operate differently from variable reluctance motors. Rather than operating by minimizing the length of the flux path between the stator poles and the rotor teeth, where the direction of current flow through the stator windings is irrelevant, these motors operate by attracting the north or south poles of the permanently magnetized rotor to the stator poles. Thus, in these motors, the direction of the current through the stator windings determines which rotor poles will be attracted to which stator poles [14].

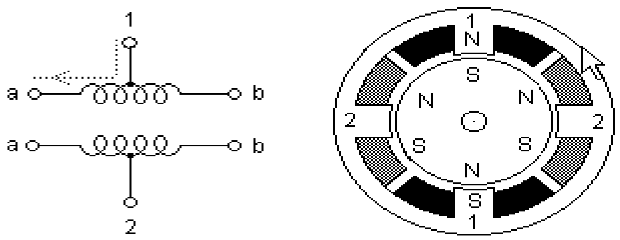

Fig.2.34. Unipolar Stepping Motors

ii. Bipolar Stepping Motors:

Bipolar stepping motors are composed of two windings and have four wires. Unlike unipolar motors, bipolar motors have no center taps. The advantage to not having center taps is that current runs through an entire winding at a time instead of just half of the winding. As a result, bipolar motors produce more torque than unipolar motors of the same size. The drawback of bipolar motors, compared to unipolar motors, is that more complex control circuitry is required by bipolar motors [14].

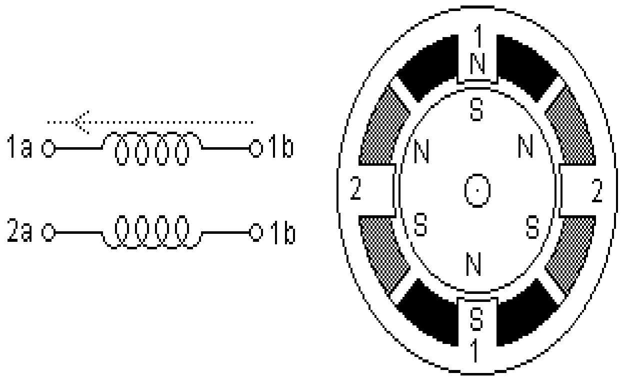

Fig.2.35. Bipolar Stepping Motors

2.6 Microcontroller:

A microcontroller is a computer with most of the necessary support chips on board. All computers have several things in common, namely:

1. A central processing unit (CPU) that executes programs.
2. B. Some random-access memory (RAM) where it can store data that is variable.

3. Some read only memory (ROM) where programs to be executed can be stored.

4. Input and output (I/O) devices that enable communication to be established

with the outside world i.e. connection to devices such as keyboard, mouse, monitors and other peripherals [15].

The basic internal designs of microcontrollers are pretty similar. Figure 2.36 shows the block diagram of a typical microcontroller. All components are connected via an internal bus and are all integrated on one chip. The modules are connected to the outside world via I/O pins [16].

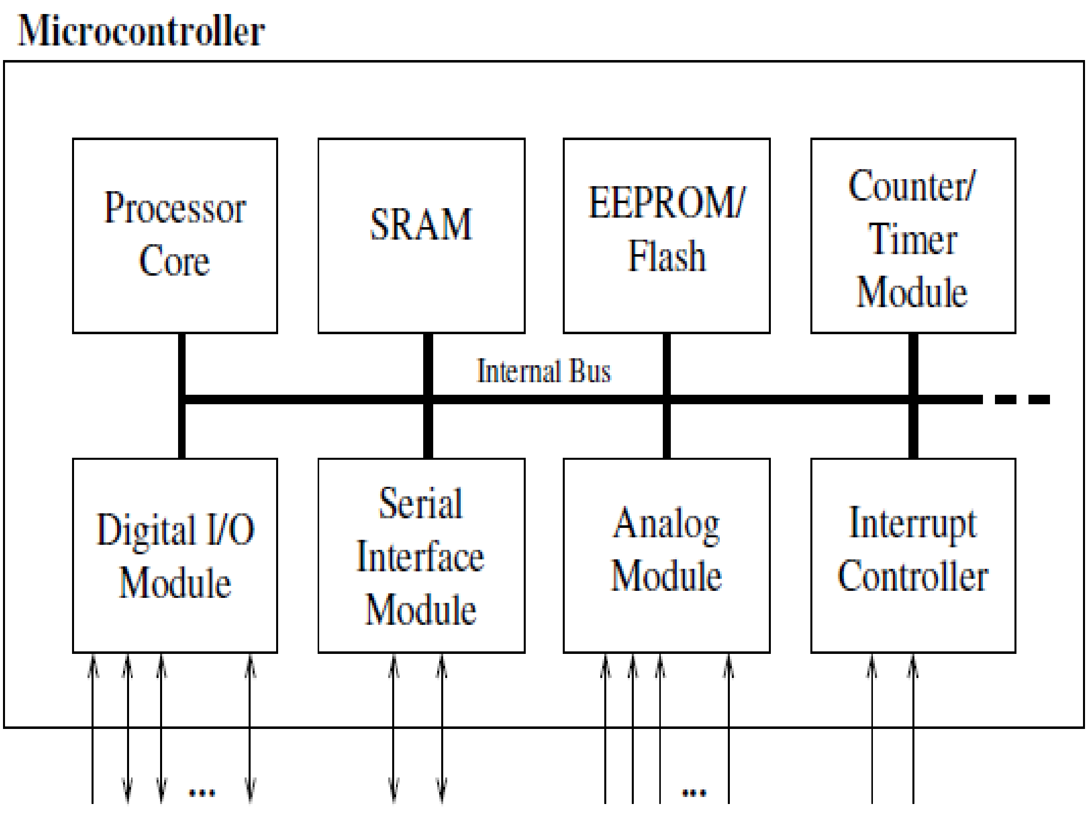

Fig.2.36. Basic Layout of A microcontroller [16].

There are a number of other common characteristics that define microcontrollers. If a computer matches a majority of these characteristics, then it can be classified to:

a) ‘Embedded’ inside some other device (often a consumer product) so that they can control the features or actions of the product. Another name for a microcontroller is therefore an (embedded controller).

b) Dedicated to one task and run one specific program. The program is stored in ROM and generally does not change.

c) A low-power device. A battery-operated microcontroller might consume as little as 50 mill watts.

A microcontroller may take an input from the device it is controlling and controls the device by sending signals to different components in the device [15].

A microcontroller is often small and low cost. The components may be chosen to minimize size and to be as inexpensive as possible. The actual processor used to implement a microcontroller can vary widely. In many products, such as microwave ovens, the demand on the CPU is fairly low and price is an important consideration. In these cases, manufacturers turn to dedicated microcontroller chips devices that were originally designed to be low-cost, small, low-power, embedded CPUs.

The Motorola 6811 and Intel 8051 are both good examples of such chips. A typical low-end microcontroller chip might have 1000 bytes of ROM and 20 bytes of RAM on the chip, along with eight I/O pins. In large quantities, the cost of these chips can sometimes be just a few pence [15].

2.6.1 Microcontroller Types:

The predominant family of microcontrollers are 8-bit types since this word size has proved popular for the vast majority of tasks the devices have been required to perform. The single byte word is regarded as sufficient for most purposes and has the advantage of easily interfacing with the variety of IC memories and logic circuitry currently available.

The serial ASCII data is also byte sized making data communications easily compatible with the microcontroller devices. Because the type of application for the microcontroller may vary enormously most manufacturers provide a family of devices, each member of the family capable of fitting neatly into the manufacturer's requirements.

This avoids the use of a common device for all applications where some elements of the device would not be used; such a device would be complex a hence expensive. The microcontroller family would have a common instruction subset but family members differ in the amount, and type, of memory, timer facility, port options, etc. possessed, thus producing cost-effective devices suitable for particular manufacturing requirements. Memory expansion is possible with off chip RAM and/or ROM; for some family members there is no on-chip ROM, or the ROM is either electrically programmable ROM (EPROM) or electrically erasable PROM (EEPROM) known as flash EEPROM which allows for the program to be erased and rewritten many times. Additional on-chip facilities could include analogue-to-digital conversion (ADC), digital-to-analogue conversion (DAC) and analogue comparators. Some family members include versions with lower pin count for more basic applications to minimize costs [15].

2.6.2 Arduino Microcontroller:

The Arduino is what is known as a Physical or embedded Computing platform, which means that it is an interactive system, that through the use of hardware and software can interact with its environment [17].

Arduino is an open source prototyping platform based on easy-to-use hardware and software, Arduino boards are able to read inputs light on a sensor, a finger on a button, or a Twitter message and turn it into an output activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language, and the Arduino Software (IDE), based on Processing [18].

Arduino was born at the Ivrea Interaction Design Institute as an easy tool for fast prototyping, aimed at students without a background in electronics and programming. As soon as it reached a wider community, the Arduino board started changing to adapt to new needs and challenges, differentiating its offer from simple 8-bit boards to products for applications, wearable, 3D printing, and embedded environments.

All Arduino boards are completely open-source, empowering users to build them independently and eventually adapt them to their particular needs. The software, too, is open-source, and it is growing through the contributions of users worldwide.

In simple terms, the Arduino is a tiny computer system that can be programmed with your instructions to interact with various forms of input and output [18].

The current Arduino board model, the Uno, is quite small in size although it might not look like much to the new observer, the Arduino system allows you to create devices that can interact with the world around you. By using an almost unlimited range of input and output devices, sensors, indicators, displays, motors, and more, you can program the exact interactions required to create a functional device.

For example, artists have created installations with patterns of blinking lights that respond to the movements of passers-by, high school students have built autonomous robots that can detect an open flame and extinguish it, and geographers have designed systems that monitor temperature and humidity and transmit this data back to their offices via text message.

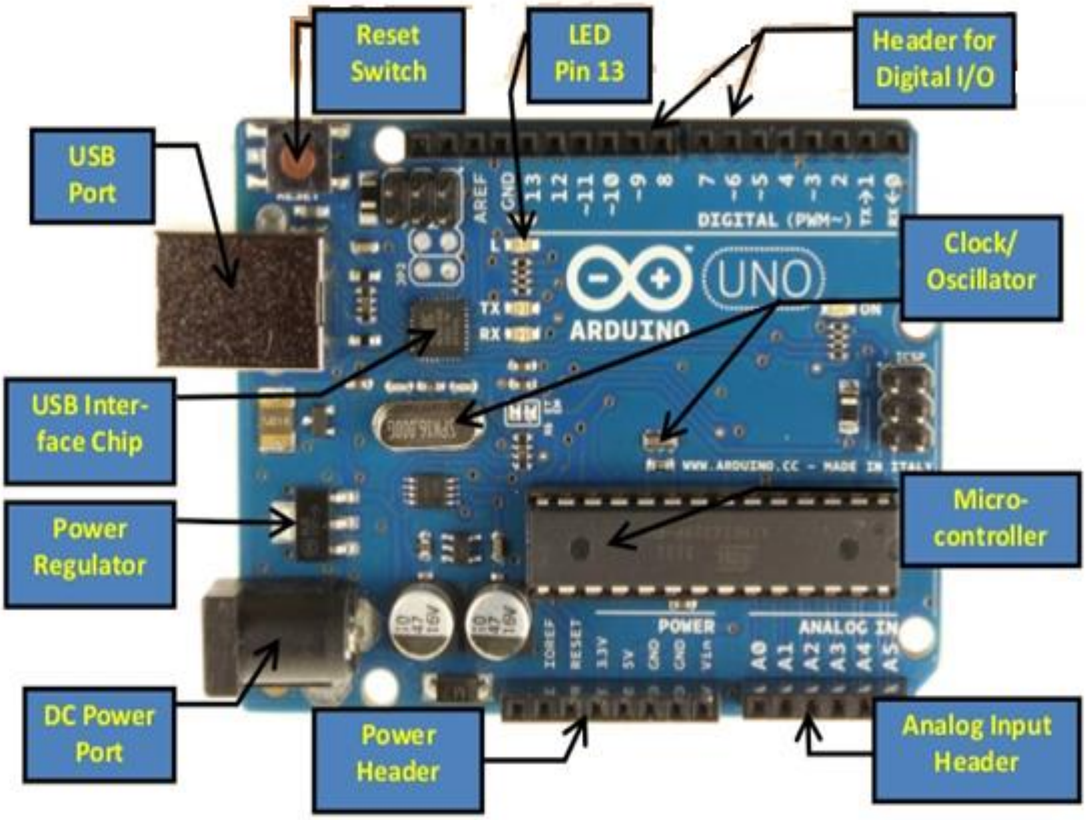

Fig 2.37. An Arduino Uno

Let’s take a quick tour of the Uno. Starting at the left side of the board, you’ll see two connectors, on the far left is the Universal Serial Bus (USB) connector.

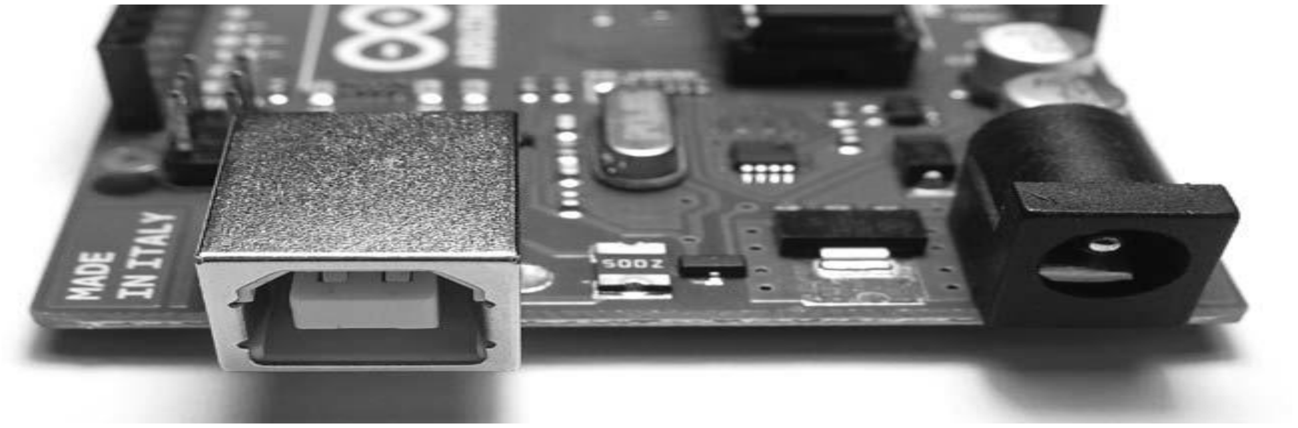

Fig 2.38. An Arduino Uno from left side

This connects the board to your computer for three reasons: to supply power to the board, to upload your instructions to the Arduino, and to send data to and receive it from a computer. On the right is the power connector. Through this connector, you can power the Arduino with a standard mains power adapter.

At the lower middle is the heart of the board: the microcontroller, as shown in the figure 2.39.

Fig 2.39. An Arduino Uno Microcontroller

The microcontroller is the “brains” of the Arduino. It is a tiny computer that contains a processor to execute instructions, includes various types of memory to hold data and instructions from our sketches, and provides various avenues of sending and receiving data [18].

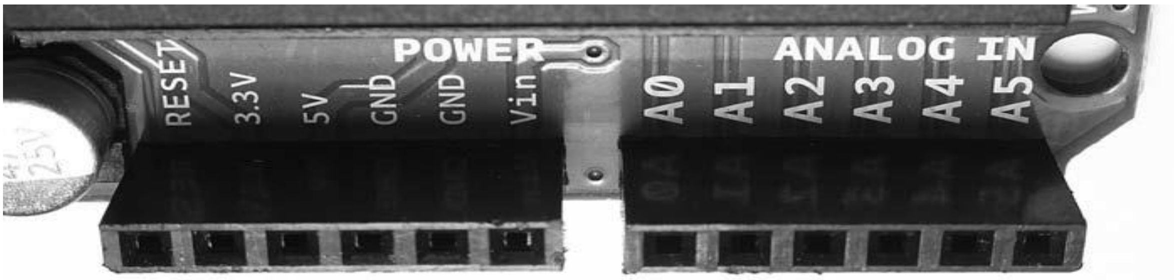

Fig 2.40. An Arduino Uno from down side

Are two rows of small sockets, as shown in the figure 2.40. The first row offers power connections and the ability to use an external RESET button. The second row offers six analog inputs that are used to measure electrical signals that vary in voltage. Furthermore, pins A4 and A5 can also be used for sending data to and receiving it from other devices [18].

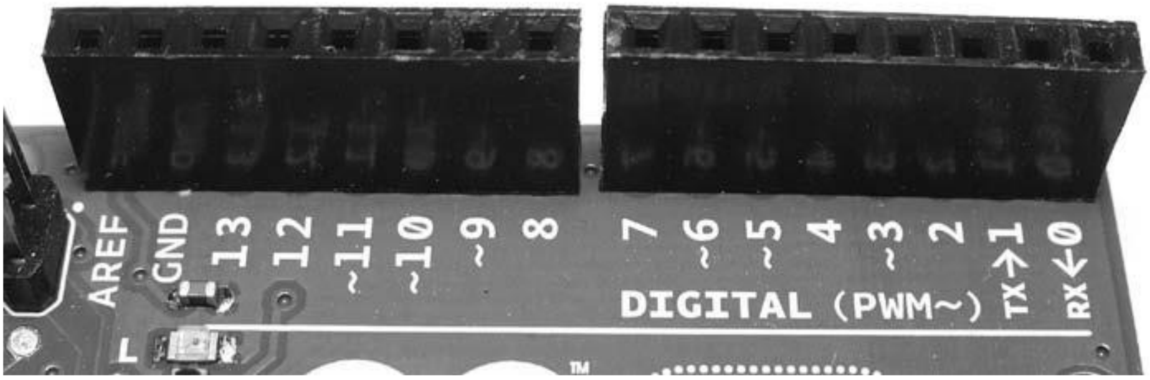

Fig 2.41. An Arduino Uno from up side

Along the top of the board are two more rows of sockets, as shown in the figure 2.41 the sockets (or pins) numbered 0 to 13 are digital input /output (I/O) pins, they can either detect whether or not an electrical signal is present or generate a signal on command.

Pins 0 and 1 are also known as the serial port, which is used to send and receive data to other devices, such as a computer via the USB connector circuitry, the pins labeled with a tilde (~) can also generate a varying electrical signal, which can be useful for such things as creating lighting effects or controlling electric motors. And also are some very useful devices called light-emitting diodes (LEDs), these very tiny devices light up when a current passes through them [18].

The Arduino board has four LEDs, one on the far right labeled ON, which indicates when the board has power, and three in another group, as shown in Figure 2.42.

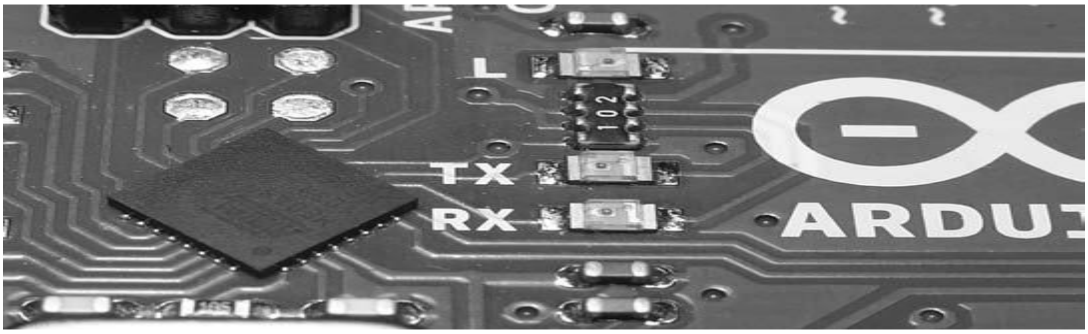

Fig 2.42An Arduino Uno light emitting diodes(LEDs)

The LEDs labeled TX and RX light up when data is being transmitted or received between the Arduino and attached devices via the serial port and USB, the L LED is for your own use (it is connected to the digital I/O pin number 13), the little black square part to the left of the LEDs is a tiny microcontroller that controls the USB interface that allows your Arduino to send data to and receive it from a computer [18].

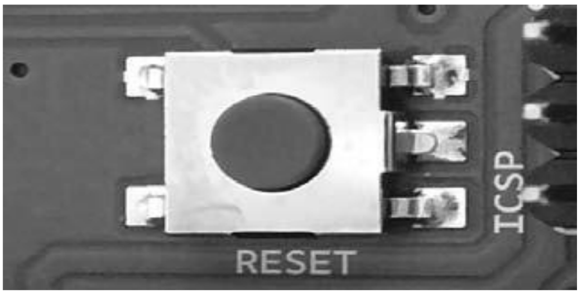

Fig 2.43. An Arduino Uno reset button

And finally, the RESET button that is shown in Figure 2.43. As with a normal computer, sometimes things can go wrong with the Arduino, and when all else fails, you might need to reset the system and restart your Arduino. This simple RESET button on the board is used to restart the system to resolve these problems.

One of the great advantages of the Arduino system is its ease of expandability that is, it’s easy to add more hardware functions. The two rows of sockets along each side of the Arduino allow the connection of a shield, another circuit board with pins that allow it to plug into the Arduino for example, the shield shown in Figure 2.44.

Fig 2.44. An Arduino Uno with Ethernet card

The shield contains an Ethernet interface that allows the Arduino to communicate over networks and the internet, with plenty of space for custom circuitry.

Notice how the Ethernet shield also has rows of sockets. These enable you to insert one or more shields on top. For example, Figure 2.45 [18].

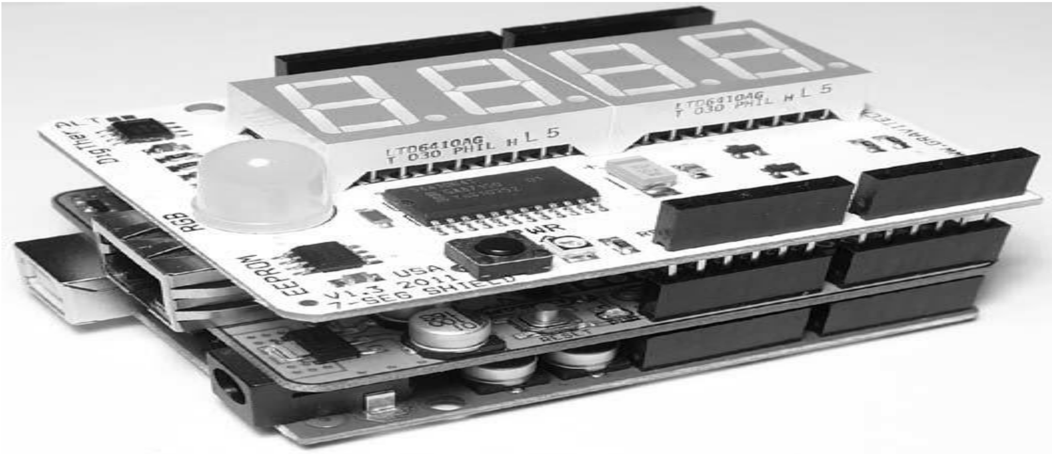

Fig 2.45. An Arduino Uno with temperature sensor card

This is another shield with a large numeric display, temperature sensor, extra data storage space, and a large LED has been inserted.

Chapter III

Hardware and Software Components of Drilling Machine

3.1 Laser Devices of Drilling Machine:

Having the right equipment to get the job done safely can mean the difference between success and failure. Laser sources are different according to the application that need to use, it's so difficult to find laser source have high energy in the local market, so the designer was used low power laser source in his design represent by a laser pointer.

Fig.3.1. Laser Pointer

The laser pointer that are using is 3v power supply and the output of the Arduino is 5v so the design used solid state relay for interfacing between the Arduino and 3v battery.

3.1.1 Solid State Relay:

A solid-state relay (SSR) is an electronic switching device that switches on or off when a small external voltage is applied across its control terminals. SSRs consist of a sensor which responds to an appropriate input (control signal), a solid-state electronic switching device which switches power to the load circuitry, and a coupling mechanism to enable the control signal to activate this switch without mechanical parts. The relay may be designed to switch either AC or DC to the load. It serves the same function as an electromechanical relay, but has no moving parts.

Packaged solid-state relays use power semiconductor devices such as thyristors and transistors, to switch currents up to around a hundred amperes. Solid-state relays have fast switching speeds compared with electromechanical relays, and have no physical contacts to wear out. Application of solid-state relays must consider their lower ability to withstand momentary overload, compared with electromechanical contacts, and their higher ON state resistance. Unlike an electromechanical relay, a solid-state relay provides only limited switching arrangements.

3.2 Gearing Stepper Motors:

This is a great first stepper motor, good for small projects and experimenting with steppers. This unipolar motor has a built in mounting plate with two mounting holes.

There are only 32 step (11.25 degree) per revolution, and inside is a 1/16 reduction gear set, (Actually its 1/16.032 but for most purposes 1/16 is a good enough approximation) what this means is that there are really 32*16.032 steps per revolution = 513 steps. The shaft is flattened so it's easy to attach stuff to it with a set screw.

A perfect first stepper motor and works well with the motor shield for Arduino.

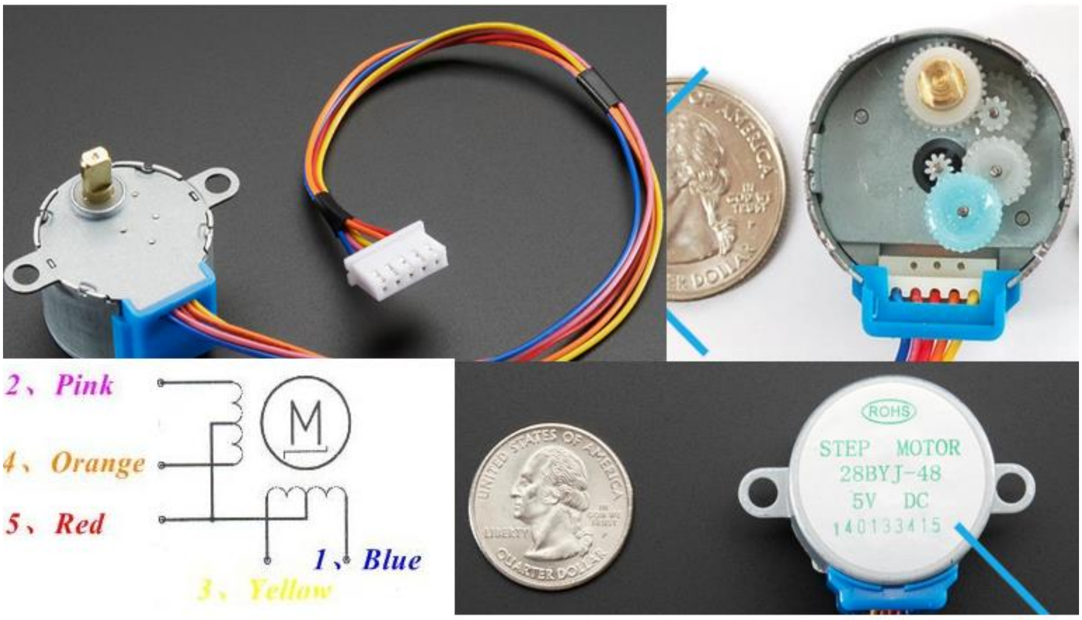

Fig.3.2. Geared Stepper Motor

The figure 3.2 showing gear stepper motor and it has a few side effects which are important to note. First, you can turn the stepper by hand but not as smoothly as an ungeared stepper. It also means you shouldn't use interleaved or micro stepping to control or it will take forever to turn. Instead use single or double stepping.

The torque is fairly high but its slower than ungeared steppers we maxed out at about 50 RPM by over driving it a bit with 9VDC. At 5V try to stick to under 25 RPM.

3.2.1 Drive Circuit of Stepper Motors:

Dedicated integrated circuits have dramatically simplified stepper motor driving. They are explains the ULN2003APG stepper motor driver and describe the drive circuit techniques used in this project.

i. **ULN2003APG**:

The ULN2003APG/AFWG Series are high voltage, high current Darlington drivers comprised of seven NPN Darlington pairs. All units feature integral clamp diodes for switching inductive loads. Applications include relay, hammer, lamp and display (LED) drivers [19].

A. Features:

1. Output current (single output): 500 mA max.
2. High sustaining voltage output: 50 V min.
3. Output clamp diodes.
4. Inputs compatible with various types of logic.
5. Package Type-APG: DIP-16pin.
6. Package Type-AFWG: SOL-16pin.
7. Input Base Resistor of ULN2003APG/AFWG is 2.7 k Ω.
8. Input Base Resistor of ULN2004APG/AFWG is 10.5 k Ω[19].

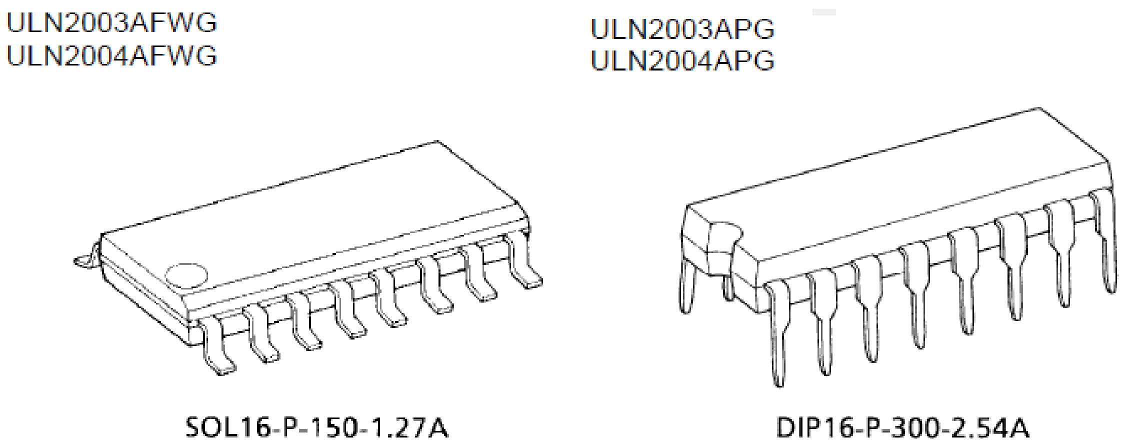

Fig.3.3. ULN2003APG/AFWG/ ULN2004APG/AFWG

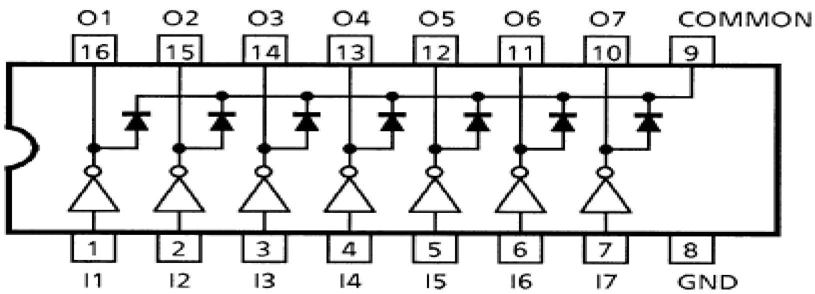

Fig.3.4. Pin Connection of ULN2004APG/AFWG (top view)

Table 3.1 Absolute maximum ratings at temperature = 25°C [15]

Characteristic		Symbol	Rating	Unit
Output Sustaining Voltage		VCE (SUS)	−0.5 to 50	V
Output Current		IOUT	500	mA/ch
Input Voltage		VIN	−0.5 to 30	V
Operating Temperature		T opr	−40 to 85	°C
Storage Temperature		T stg	−55 to 150	°C
Power Dissipation	APG	PD	1.47	W
	AFWG		1.25 (Note)	

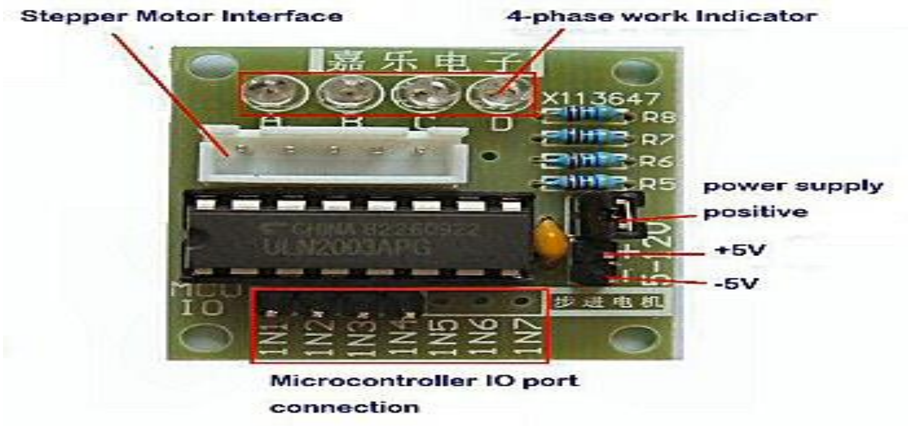

Fig.3.5. ULN2003APG with interface card used to driving stepper motor

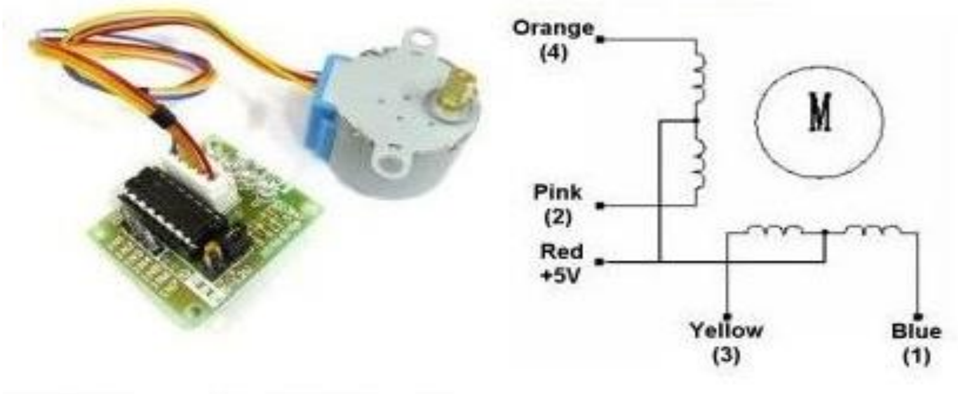

Fig.3.6. ULN2003APG connected with stepper motor

3.3 Arduino Uno:

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller, simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter. "Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform.

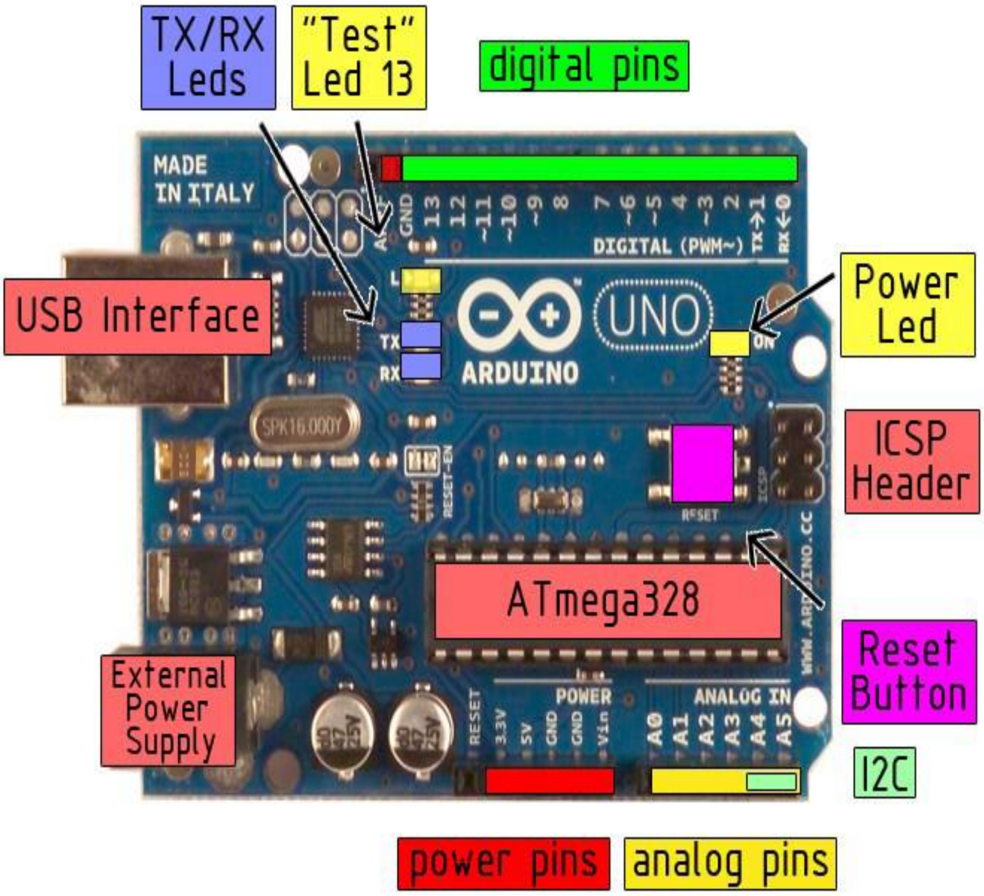

Fig.3.7. Arduino Uno

3.3.1 Arduino Uno Features:

a) Microcontroller ATmega328 .
b) Operating Voltage 5V.
c) Input Voltage (recommended) 7-12V.
d) Input Voltage (limits) 6-20V.
e) Digital I/O Pins 14 (of which 6 provide PWM output).
f) Analog Input Pins 6.
g) DC Current per I/O Pin 40 mA.
h) DC Current for 3.3V Pin 50 mA.
i) Flash Memory 32 KB of which 0.5 KB used by.
j) Bootloader.
k) SRAM 2 KB.
l) EEPROM 1 KB.
m) Clock Speed 16 MHz.

3.4 Method of Design:

The basic object of this thesis is design and control of accurate drilling machine for this using Arduino microcontroller and tow of gear stepper motors for controlling drill position in four directions, two directions are external movement and another for an internal position (drilling position) and using ULN2003APG for driving the tow of stepper motors and using a laser device for drilling the different materials.

For design simple accurate drilling machine, needed to interface between the operator and machine to entering data of drill position, so using serial connection for entering drill position data from a personal computer through the serial monitor to operate drilling machine.

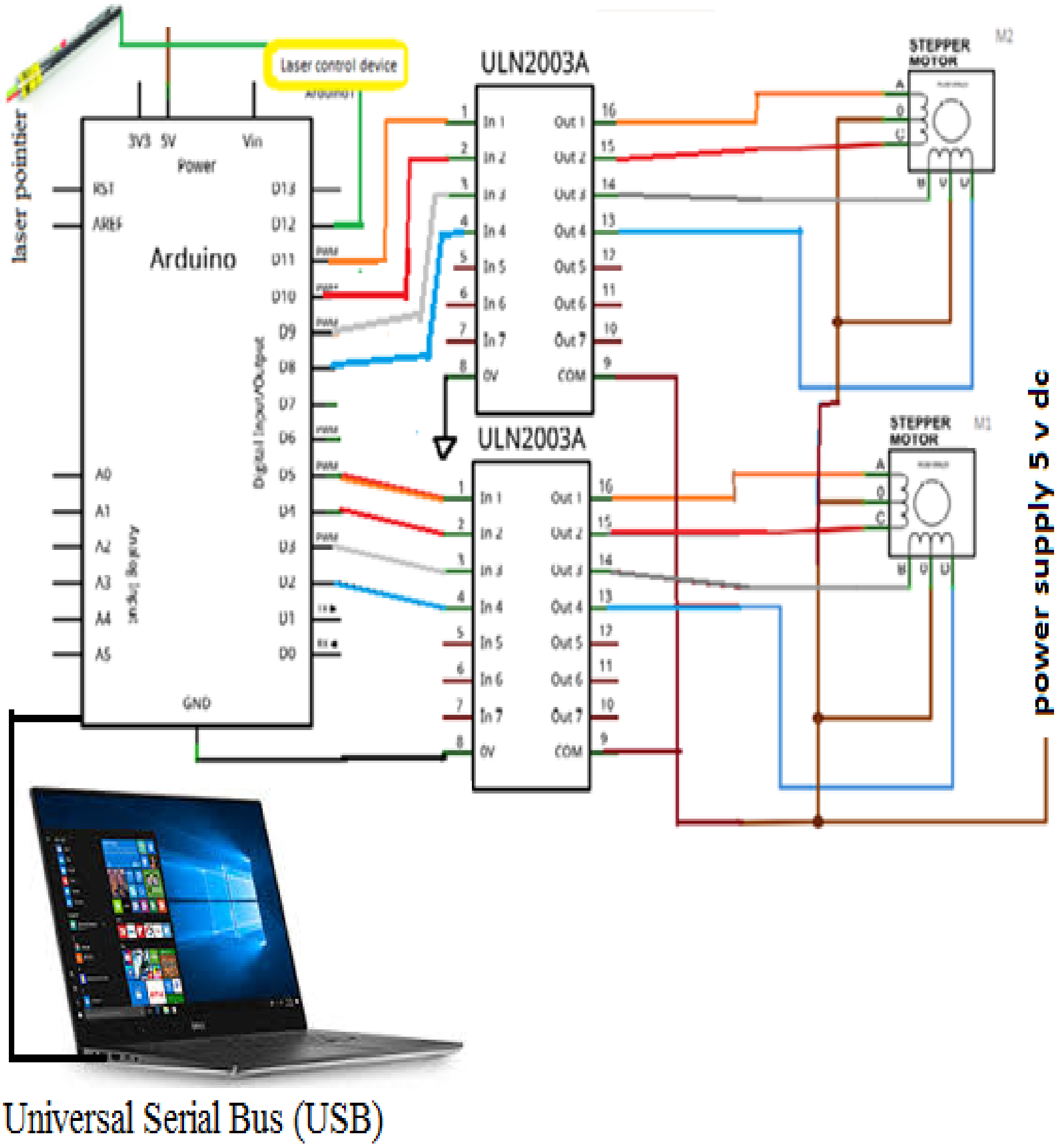

Fig 3.8. The electrical design circuit of drill machine

3.4 Control of Design:

The companion to the Arduino hardware is the software, a collection of instructions that tell the hardware what to do and how to do it. This program is the integrated development environment (IDE). The IDE software is installed on a personal computer and use to compose and send sketches to the Arduino board.

When open (IDE) software program and uploading program of drilling machine then the operator drill machine can open the serial monitor and controlling the design by using machine guide to send position data of drilling through serial monitor.

Fig 3.9. Serial Monitor

3.4 Drilling Machine Design:

A complete design is presented in Fig. 3.10 when one of the stepper motor is the use of move external arm and another one is to move the internal arm.

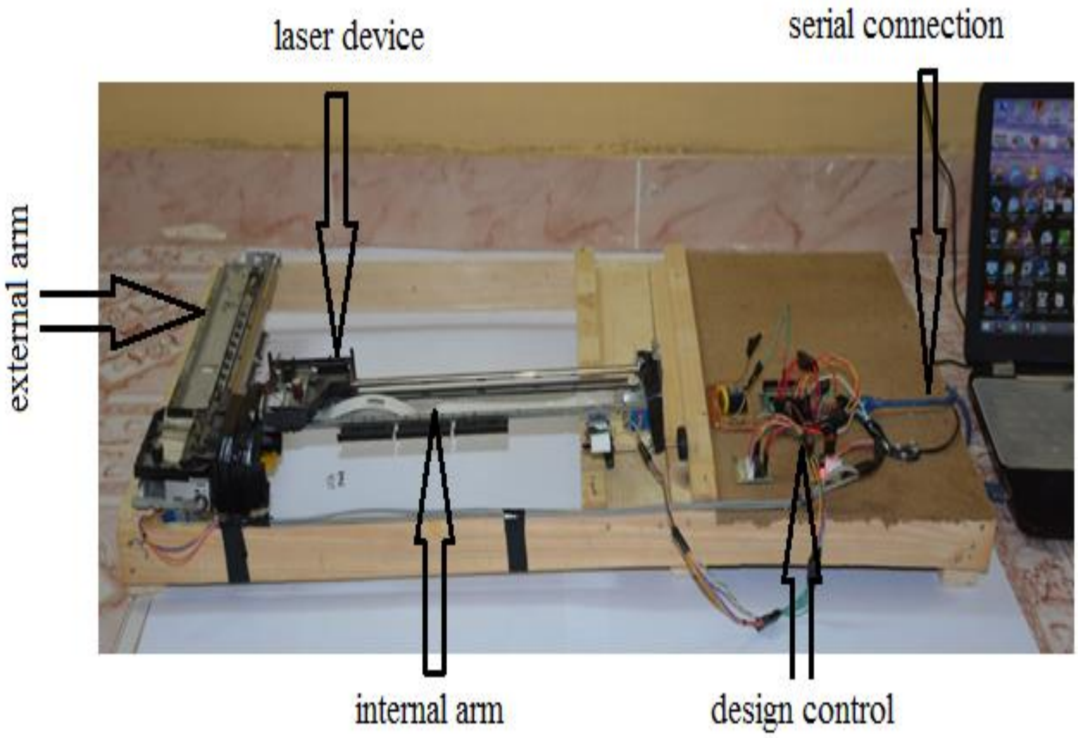

Fig 3.10. Drilling Machine Design

The laser device is moving with the upper part of internal arm to detect the drill position. The total area that drill machine can reach it is (30*30) cm.

3.5 Drilling Machine Flowchart:

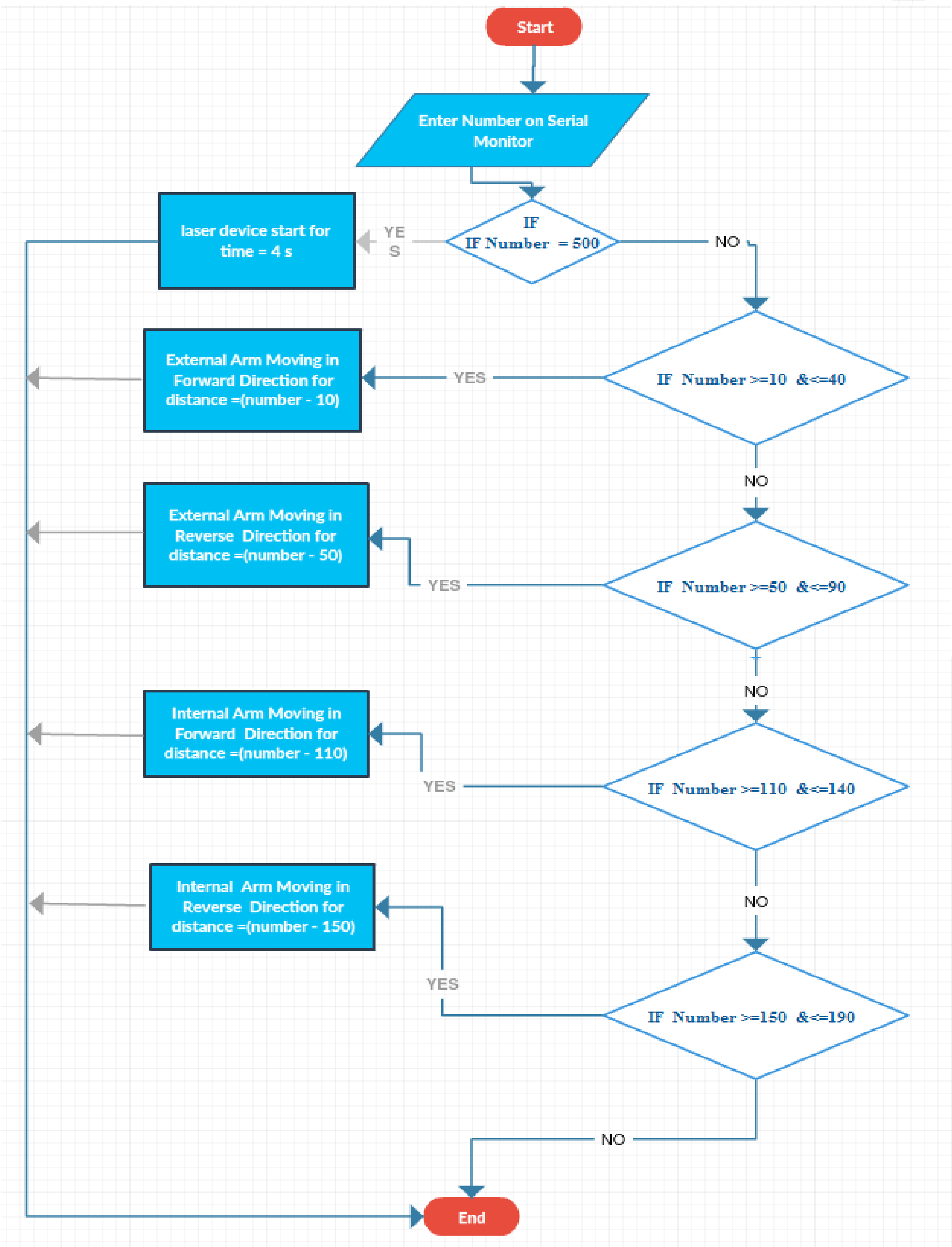

Fig 3.11. Accurate Drilling Machine Flowchart

This design has more advantage than traditional machines, it can be used for cut material to different size, this feature is added in software program to make design able to cut different materials, and the cutting operation flowchart is represented in the figure below.

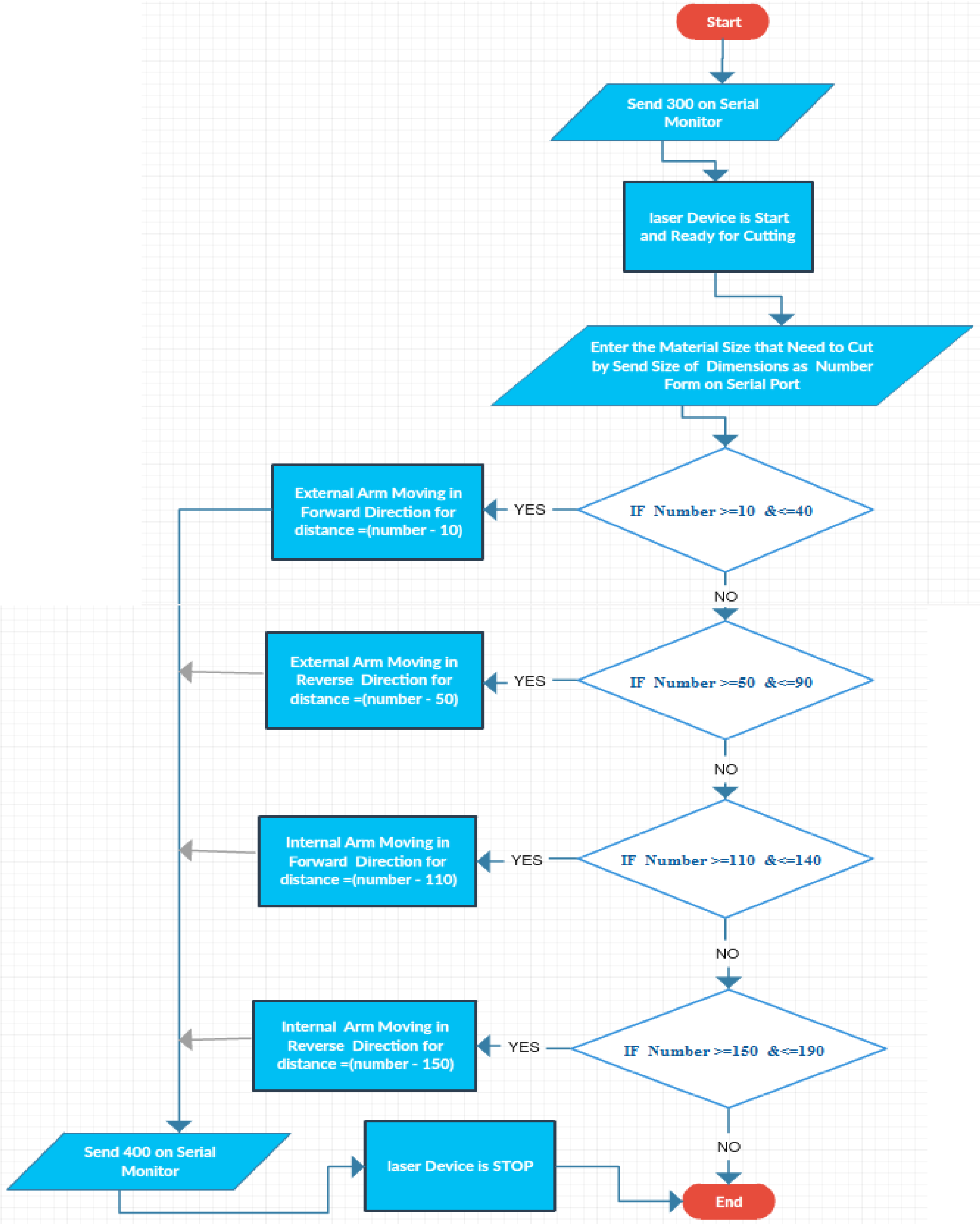

Fig 3.12. Drilling Machine do cutting job flowchart

Chapter IV
Result & Discussion

4.1 Result:

The project accurate drill machine by using microcontroller was designed such that the drilling position is controlled automatically by microcontroller based system.

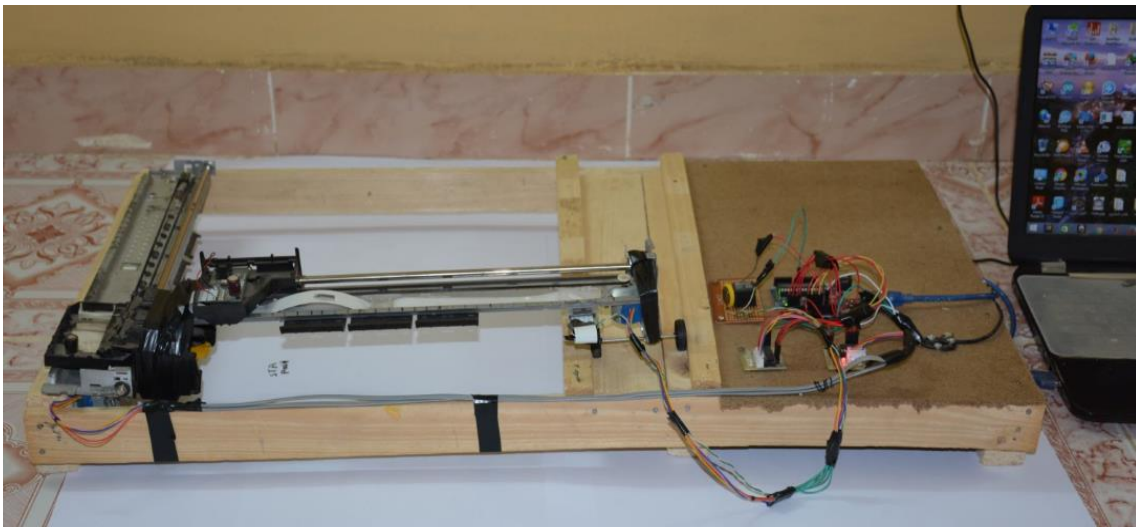

Fig 4.1 Laser Drilling Machine

When the design is connected to a personal computer and serial monitor was opened then it can be control of drill position by send position parameter as number form. First must be the operator convert The amount of movement into integer number, then put the number in serial monitor and send it, when number was sent, the program directly checks it, if it was found (number =500) then the laser indicator it was run.

If the number did not equal (500) the next test is (number >= 10 && number <= 40) then the external arm of drill machine is move in forward direction around (number -10) cm ,else if (number >= 50 && number <= 90) then the external arm of drill machine is move in reverse direction around (number -50) , else if (number >= 110 && number <= 140) then the internal arm of drill machine is move in forward direction around (number -110) , else if (number >= 150 && number <= 190) then the internal arm of drill machine is move in reverse direction around (number -150) .

Also with this machine can cut material to different size, when the operator need to cut material must be start the laser device in a mark of indentation and then move the machine according to dimensions of material that require for cut, after cut the material, the laser device must be stopped

This design can be move in area around (30*30) cm.

4.2 Discussion

From previous chapter we get the flowing point.

The accurate drilling machine can be moved around the amount of area (30*30) cm and it can be setting the resolution of movement, according to job that need it to do by change the delay of waiting between each step and another of stepper motors.

In this project the program set the delay between each step and another to give 1 cm displacement between each one number on serial monitor, and make base number for each direction. For explaining that put the design on start point.

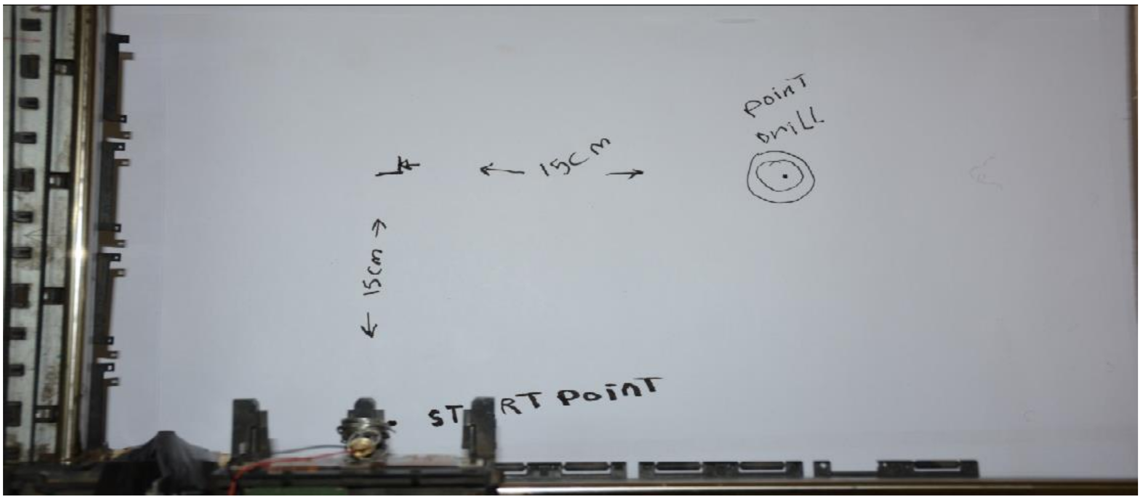

Fig 4.2 Laser drilling machine on start point

If needed to drill hole like the drill point that shown on the above figure must be move the external arm around 15 cm in forward direction by send number 25 through the serial monitor.

The second step is send number 125 on serial monitor, then the internal arm of drill machine is moving around 15 cm in forward direction.

The last step is send number 500 on serial monitor, then the laser device is running for 4 s to make hole, on this project used a laser pointer as simulation to indicate of drill position.

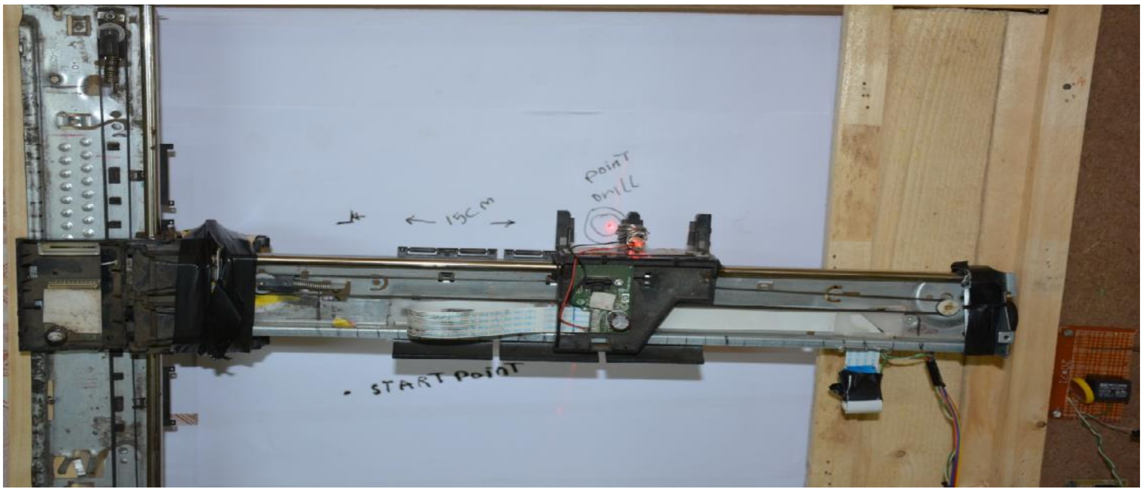

Fig 4.3 Laser drilling machine running

This design can be used for cutting the martial by starting laser device in continues mode and move the external and the internal arm to make the desired shape.

Compares this design with other drilling processes. This design has many advantages that make it very useful in practical hole drilling operations such as:

A. High throughput leading to low cost processing.
B. Noncontact and no tool wear.
C. Material hard to drill by other methods, such as ceramics and gemstones can be drilled with high quality.
D. Heat affected zone is small around the hole.
E. Smaller holes can be drilled in thin materials.
F. Capacity for a high degree of beam manipulation, including the ability to drill at shallow angles and to drill shaped holes.
G. Highly accurate and consistent process quality.
H. The same laser system can be used for multiple purposes such as cutting, drilling, and marking.

It is economical to drill relatively small holes that can be drilled through by lasers in a short period. Larger diameter holes can be drilled by mechanical method. Aspect ratio >25 is usually a challenge for laser drilling, drilling of thick sections can be very difficult due to multiple reflection and the limited depth of focus of the laser beam.

Chapter V
Conclusion &Recommendations

5.1 Conclusion:

In this thesis we are design accurate drilling machine by using Arduino microcontroller that control of tow geared steeper motor to moving tow mechanical arm according to drill position on workpiece and using laser technique for drilling workpiece.

For interfacing between machine operator and machine the design using serial monitor to control of all drilling machine.

This design has various advantage and modern and simple to use, and it very cheap and has very accurate resolution and it can be change the job from drilling to cutting by using cut guide.

Drilling by laser techniques also has more advantage than traditional drilling machines. laser drilling process does not physically contact the material that it is working with, unlike other more conventional drills. Laser drilling allows for highly accurate and consistent results. One laser drilling machine can perform multiple functions and work with multiple materials.

This design also used for cutting by emission device to focus a highly concentrated stream of photons onto a small area of a workpiece and cut precise designs out of the material and can make highly accurate cuts with a quality finish.

5.2 Recommendations:

We recommend control drilling machine by using numeric keypad, by using more than one Arduino or use bipolar steeper motor to make design more simplest and useful.

Also we recommend to use portable power supply for the machine to easy move it between different area and make it modern.

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Appendix

Integrated development environment (IDE) program code

```
. */
Accurate Drill Machine Using Arduino
 This sketch is written to Accurate control of position in Drill Machine
 Qualification is M.Sc Program Mechatronics Engineering
 Batch 07 Atbara
 Parts required:
 tow stepper motors
 tow ULN2003APG driver
 mechanical parts movement
 laser pointer
 power supply 5 volt dc
Created 1 September 2016
 by  Muaaz Mohammed Elhassan Atitalaa
/*
 //include the stepper library
#include <Stepper.h>
long number = 0;// to use the Serial Monitor to accept long-
long a = 0;     //  -variables and numbers larger
int motorPin1 = 2;//digital bin 2 used to connect to stepper motor 1 driver
int motorPin2 = 3;//digital bin 3 used to connect to stepper motor 1 driver
int motorPin3 = 4;//digital bin 4 used to connect to stepper motor 1 driver
int motorPin4 = 5;//digital bin 5 used to connect to stepper motor 1 driver
int motorPin5 = 8;//digital bin 8 used to connect to stepper motor 2 driver
int motorPin6 = 9;//digital bin 9 used to connect to stepper motor 2 driver
int motorPin7 = 10;//digital bin 10 used to connect to stepper motor 2 driver
```

```
int motorPin8 = 11;//digital bin 11 used to connect to stepper motor 2 driver
int drilling =  12;//digital bin 12 used to operate laser pointer
int z;// variable to make delay off counter for laser pointer
int p;//variable to make delay off counter for tow stepper motors
int delayTime = 10;// delay time = 10 Millisecond
void setup()
{
  pinMode(motorPin1, OUTPUT);//Configure bin 2 as output
  pinMode(motorPin2, OUTPUT);//Configure bin 3 as output
  pinMode(motorPin3, OUTPUT);//Configure bin 4 as output
  pinMode(motorPin4, OUTPUT);//Configure bin 5 as output
  pinMode(motorPin5, OUTPUT);//Configure bin 8 as output
  pinMode(motorPin6, OUTPUT);//Configure bin 9 as output
  pinMode(motorPin7, OUTPUT);//Configure bin 10 as output
  pinMode(motorPin8, OUTPUT);//Configure bin 11 as output
  pinMode(drilling, OUTPUT);//Configure bin 12 as output
 Serial.begin(9600);// initialize serial communication:
}
void loop()
{
number = 0; // zero the incoming number ready for a new read
Serial.flush(); // clear any "junk" out of the serial buffer before waiting
while (Serial.available() == 0)
{
 //do nothing until something comes into the serial buffer،
 //when something does come in, Serial.available will return how many
 //characters are waiting in the buffer to process
```

```
}
 //one character of serial data is available, begin calculating
while (Serial.available() > 0)
{
 //move any previous digit to the next column on the left؛
 //in other words, 1 becomes 10 while there is data in the buffer
number = number * 10;
 //read the next number in the buffer and subtract the character 0
 //from it to convert it to the actual integer number
a = Serial.read() - '0 ' ;
 //add this value a into the accumulating number
number = number + a ;
 //allow a short delay for more serial data to come into Serial.available
delay(500)
}
if (number  == 500)
{
  for (int  p= 1 ; p < 400 ; p ++ )
{
digitalWrite( drilling, HIGH؛) ;
Serial.print("drilling؛" ) ;
delay(delayTime)
 //if received number from serial monitor = 500 then the digital bin 12
 //become high and laser pointer was started and waiting p counter to
 //make delay off
}
}
```

```
elseif (number  == 300)
{
digitalWrite( drilling, HIGH؛) ;
Serial.print("cutting؛" ) ;
 //if received number from serial monitor = 300 then the digital bin 12
 //become high and laser pointer works continuously for cutting
}
if (number  == 400)
{
digitalWrite( drilling, LOW؛) ;
 //if received number from serial monitor = 400 then the digital bin 12
 //become low and laser pointer was stopped
}
else if (number >= 10 && number <= 40(
{
   for (int  z= 10 ; z < number ; z ++)
{
    for (int  z= 1 ; z <180 ; z++ )
{
  digitalWrite(motorPin1, HIGH);
  digitalWrite(motorPin2, LOW);
  digitalWrite(motorPin3, LOW);
  digitalWrite(motorPin4, LOW);
  delay(delayTime);؛
  digitalWrite(motorPin1, LOW؛(
  digitalWrite(motorPin2, HIGH؛(
  digitalWrite(motorPin3, LOW؛(
```

```
  digitalWrite(motorPin4, LOW؛(
  delay(delayTime؛(
  digitalWrite(motorPin1, LOW؛(
  digitalWrite(motorPin2, LOW؛(
  digitalWrite(motorPin3, HIGH؛(
  digitalWrite(motorPin4, LOW؛(
  delay(delayTime؛(
  digitalWrite(motorPin1, LOW؛(
  digitalWrite(motorPin2, LOW؛(
  digitalWrite(motorPin3, LOW؛(
  digitalWrite(motorPin4, HIGH؛(
  delay(delayTime ؛(
 //if received number from serial monitor >=10 & <=40 then the stepper motor 1
 //was moved in forward direction  and we are adjust the delay of moving to
//become each one number moved the laser pointer one cm in work pica
}
}
}
else if (number >= 50 && number <= 90)
{
    for (int  z= 50 ; z < number ; z++)
{
      for (int  z= 1 ; z <180 ; z ++)
{
  digitalWrite(motorPin1, LOW);
  digitalWrite(motorPin2, LOW);
  digitalWrite(motorPin3, HIGH);
```

```
  digitalWrite(motorPin4, LOW);
  delay(delayTime);
  digitalWrite(motorPin1, LOW);
  digitalWrite(motorPin2, HIGH);
  digitalWrite(motorPin3, LOW);
  digitalWrite(motorPin4, LOW);
  delay(delayTime);
  digitalWrite(motorPin1, HIGH);
  digitalWrite(motorPin2, LOW);
  digitalWrite(motorPin3, LOW);
  digitalWrite(motorPin4, LOW);
  delay(delayTime);
  digitalWrite(motorPin1, LOW);
  digitalWrite(motorPin2, LOW);
  digitalWrite(motorPin3, LOW);
  digitalWrite(motorPin4, HIGH);
  delay(delayTime);
 //if received number from serial monitor >=50 & <=90 then the stepper motor 1
 //was moved in reverse direction  and we are adjust the delay of moving to
//become each one number moved the laser pointer one cm in work pica
}
}
}
else if (number >= 110 && number <= 140)
{
   for (int  z=  110 ; z < number ; z ++)
{
```

```
   for (int  z= 1 ; z <180 ; z ++)
{
  digitalWrite(motorPin5, HIGH);
  digitalWrite(motorPin6, LOW);
  digitalWrite(motorPin7, LOW);
  digitalWrite(motorPin8, LOW);
  delay(delayTime);
  digitalWrite(motorPin5, LOW);
  digitalWrite(motorPin6, HIGH);
  digitalWrite(motorPin7, LOW);
  digitalWrite(motorPin8, LOW);
  delay(delayTime);
  digitalWrite(motorPin5, LOW);
  digitalWrite(motorPin6, LOW);
  digitalWrite(motorPin7, HIGH);
  digitalWrite(motorPin8, LOW);
  delay(delayTime);
  digitalWrite(motorPin5, LOW);
  digitalWrite(motorPin6, LOW);
  digitalWrite(motorPin7, LOW);
  digitalWrite(motorPin8, HIGH);
  delay(delayTime);
 //if received number from serial monitor >=110 & <=140 then the stepper motor 1
 //was moved in forward direction  and we are adjust the delay of moving to
//become each one number moved the laser pointer one cm in work pica
}
}
```

```
}
   else if (number >= 150 && number <= 190)
{
    for (int  z= 150 ; z < number ; z ++)
{
      for (int  z= 1 ; z <180 ; z ++)
{
  digitalWrite(motorPin5, LOW);
  digitalWrite(motorPin6, LOW);
  digitalWrite(motorPin7, HIGH);
  digitalWrite(motorPin8, LOW);
  delay(delayTime);
  digitalWrite(motorPin5, LOW);
  digitalWrite(motorPin6, HIGH);
  digitalWrite(motorPin7, LOW);
  digitalWrite(motorPin8, LOW);
  delay(delayTime);
  digitalWrite(motorPin5, HIGH);
  digitalWrite(motorPin6, LOW);
  digitalWrite(motorPin7, LOW);
  digitalWrite(motorPin8, LOW);
  delay(delayTime);
  digitalWrite(motorPin5, LOW);
  digitalWrite(motorPin6, LOW);
  digitalWrite(motorPin7, LOW);
  digitalWrite(motorPin8, HIGH);
  delay(delayTime);
```

```
 //if received number from serial monitor >=50 & <=90 then the stepper motor 1
 //was moved in reverse direction  and we are adjust the delay of moving to
//become each one number moved the laser pointer one cm in work pica
}
}
}
}
```