Development of Embedded based Anti-Collision Technique for Medical LINAC (Linear Accelerator) Machine

A Thesis report submitted in partial fulfillment of the requirements for the award of degree of

MASTER OF ENGINEERING

IN

ELECTRONICS INSTRUMENTATION & CONTROL

Submitted by

AVINASH SINGH
8044207

Under the Guidance of

Mr. MANDEEP SINGH
Lecturer, EIED
T.I.E.T, Patiala

Department of Electrical and Instrumentation Engineering
THAPAR INSTITUTE OF ENGINEERING & TECHNOLOGY
(Deemed University), PATIALA – 147004, INDIA

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CERTIFICATE

This is to certify that the thesis titled, **"Development of Embedded based Anti-collision technique for Medical LINAC machine"** being submitted by **Mr. AVINASH SINGH,** in partial fulfillment of the requirement for the award of degree of **MASTER OF ENGINEERING(Electronics Instrumentation & Control)** at **Electrical And Instrumentation Engineering Department**, **Thapar Institute of Engineering and Technology (Deemed University), Patiala,** is a bonafide work carried out by him under our guidance and supervision and that no part of this thesis has been submitted for the award of any other degree.

(Mr. MANDEEP SINGH)
Lecturer, E.I.E.D.
T. I. E. T. Patiala-147004

(Mrs. MANBEER KAUR)
HEAD, E.I.E.D.
T. I. E. T. Patiala-147004

(Dr T.P. SINGH)
Dean Academic Affairs
T.I.E.T. Patiala-147004

DECLARATION

I hereby declare that the Thesis entitled “Development of Embedded based Anti-collision Technique for Medical LINAC machine” is an authentic record of my own work carried out as requirements for the award of degree of M.E. (Electronics Instrumentation and Control) at Thapar Institute of Engineering & Technology (Deemed University), Patiala, under the guidance of Mr. Mandeep Singh, Lecturer (EIED) during January to June, 2006.

Avinash Singh

Date: …………… **8044207**

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An understanding of the work like this is never the outcome of the efforts of a single person. I take this opportunity to express my profound sense of gratitude and respect to all those who helped me through the duration of this thesis.

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Avinash Singh

8044207

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ABSTRACT

In Linear Accelerator, there may be possibility of misalignments of machine elements, which can cause an accident to patient and machine itself. Hence tight limits are imposed on machine tolerance, design parameters and methods of machine operation. The objective of the work is to improve the work efficiency of machine and high operation speed, accuracy and the most important factor is safety of patient & equipment. Microcontroller provides convenient control, well-designed display, and more comprehensive diagnostics and error logging can increase safety. In order to focus more sharply our efforts to the possible impact of machine-Patient collision problem, we have developed a formula and list of entries that have the potential for the most serious consequence for the patient machine collision. The calculations are done in such a way that there is no chance of collision and result in patient and equipment safety.

Our method correctly confirmed clearance for patient couch and gantry. In conclusion, we have developed a embedded based device form lookup table method for collision detection that is accurate, easy to implement, and computationally inexpensive.

Chapter-1

Introduction

Cancer is one of the leading causes of death in the world. The medical linear accelerator (LINAC) has of late, become the principal treatment mode in most radiation therapy practices in the developed world. The LINAC provides radiation oncologists precision, versatility efficiency and reliability. The medical linear accelerators consist of four major components:

1. An electronics cabinet called a “stand” housing a microwave energy-generating source.

2. A rotating Gantry containing the accelerator structure that rotates around the patient;

3. An adjustable treatment couch;

4. Operating electronics;

A radiotherapy facility has essentially a medical linac machine, a specially constructed treatment room and auxiliary systems necessary for machine operation. There are three separate entities, i.e. the patient, the machine and the room, which are to be accurately inter-related to provide the treatment. For this purpose, the concept of “isocentre” has been evolved . The isocentre is a point in space located at a distance of 100 cm from the x-ray target. The patient setting and delivery of dose has not to deviate more than + 1 mm from the marked region of the diseased tissue. As such, the variation in isocentre at different settings of the machine must lie within a sphere of 1- mm radius.[1]

Previous work done by Hua C, Chang J, Yenice K, Chan M, Amols H [2], have stated that the Gantry-couch collision is a serious concern for treatment planning of the linear accelerator (linac) based stereotactic radiosurgery (SRS). The ability to detect collision at the time of planning eliminates the need for backup plans and preserves the useful beam angles that would be deemed unsafe and discarded otherwise. In this study, we have developed a simple analytical method for collision detection with the use of look-up table. The collision detection is also mathematically solved by determining whether two facets in three-dimensional space, representing gantry and couch surfaces, intersect with each other or not. So there are two ways to solve the problem i.e develop the code with mathematical formula and with look-up table.

Our method correctly confirmed clearance for patient couch and gantry. In conclusion, we have developed an analytical method for collision detection that is accurate, easy to implement, and computationally inexpensive.

1.1 Goal

The goal of this work is to develop an Anticollision system using look-up table with the help of microcontroller which can control the patient couch more accurately and fast than any other existing manual measurement system.

1.2 Purpose

The purpose of this work is to:

1) make anti-collision zone.

2) make an embedded portable device.

3) make a device with high speed of response.

4) make a device with very low component cost.

1.3 Need for an Anti-collision System

Every mechanism or machine, which have moving parts, needs some safety measures, particularly, if it interacts with human beings. The human errors and system failures (mechanical, electrical and electronic), may give rise to uncontrolled and unforeseen movement of gantry and the patient couch. Several recently occurred machine patient accidents have focused attention on the serious consequences of equipment failures in linear accelerator treatment units.

1.4 Analysis of the problem

Using medical accelerators for treating cancerous is one of the most difficult things to the analysis of hazards for these machines. Because the treatment that is delivered by medical accelerator is implicitly hazardous, the radiation treatment even when prescribed appropriately and when delivered exactly as prescribed, has some probability (1-5%) of serious treatment related complications and that complication rate is accepted by both patient and physician as the price that must be paid for the possible higher tumor control response rate due to therapy. Therefore all risks associated with the use of the accelerator to the patient, machine, operator and general public must be viewed in relationship to these relative high rates of complication.[1]

Previously, we have discussed different types of hazards and among all of them, collision between patient and machine is one of the most dangerous. So particular attention should be taken to assure the safety of patients from the risk of collisions with the machine parts. In order to protect the damage caused by this collision, it is important to know the need /role of anti- collision system. [2,3]

1.5 Organization of Thesis

Chapter one deals with the introduction to the topic of thesis and its organization. Chapter two is literature review to the related topics, containing various details of radiotherapy, Linac and Microcontroller. Chapter three is about the Medical LINAC Machine. Chapter four includes the hardware description of the system like Microcontroller, LCD stepper motor etc. Chapter five describes in detail the software designed microcontroller base anti-collision system. Chapter six spells out the results, discussion, conclusion and future scope.

Chapter-2

Literature Review

Developments in Anti-collision system

Hua C, Chang J, Yenice K, Chan M, Amols H [2] have stated that the Gantry-couch collision is a serious concern for treatment planning of the linear accelerator (linac) based stereotactic radiosurgery (SRS). The ability to detect collision at the time of planning eliminates the need for backup plans and preserves the useful beam angles that would be deemed unsafe and discarded otherwise. In this study, we have developed a simple analytical method for collision detection with the use of quick machine-specific measurements. The collision detection is mathematically solved by determining whether two facets in three-dimensional space, representing gantry and couch surfaces, intersect with each other or not. A computer code was implemented and tested on a Varian linac 600C linac equipped with a Brain Lab micro multi leaf collimator (MLC) device. To measure machine-specific parameters, the lesion isocenter was set to the origin of the stereotactic coordinate system. Couch, gantry, and collimator were subsequently translated and rotated to study the clearance of various beam arrangements and lesion locations. Predicted results were verified at the machine. Our method correctly confirmed clearance for a retrospective study. It also accurately predicted the collisions for all ten artificially created cases.

Sunil Hadap, Dave Eberle, Pascal Volino, Ming C. Lin, Stephane Redon, Christer Ericson [3] gave methodologies in collision detection. In addition more advanced or recent topics such as continuous collision detection, ADFs, and using graphics hardware will be introduced. When appropriate the methods discussed will be tied to familiar applications such as rigid body and cloth simulation, and will be compared. The course is a good overview for those developing applications in physically based modeling, VR, haptics, and robotics.

Felix G. Hamza-Lup, Larry Davis, Omar A. Zeidan [4] have described that the One of the biggest concerns in external treatment planning is the collision avoidance of the treatment Linear Accelerator (LINAC®) components such as gantry(G),table (T),collimator(C), and any other auxiliary components such as fixation devices etc, with the patient. Some external treatment plans require complex components of the above GTC combinations. Author presents a preliminary design and implementation of a 3D-graphical tool for the detection of potential gantry-collimator- couch collision in external treatment planning. The graphical tool uses the Virtual Reality Modeling Language (VRML) to model the exact geometry of any treatment machine by reading its manufacturer's CAD design files. The tool can be used as a stand-alone program or embedded in the Eclipse treatment planning system.

Miltiadis F. Tsiakalos, Eduard Schrebmann, Kiki Theodorou, and Constantin Kappas [5] have described that the "room's eye view" graphical simulation program with an automated collision detection option, to assist a treatment planning user to visualize the treatment setup checking at the same time the feasibility of his plan. The program simulates the treatment process using accurate three-dimensional graphical models of the gantry, table, and that of an average patient. When a collision takes place a warning message is displayed. In this paper a software tool is developed that can be used as a stand-alone program. The visualization of the treatment fields prior to treatment permits the geometric feasibility of the plan, thus adding one more step toward the automation of the treatment process.

P.C. Cacciabue, M. Martinetto [6] has described that the EUCLIDE project (Enhanced human machine interface for on vehicle integrated driving support system), which aims of developing a driving support system to be helpful in reduced visibility. This paper focuses on the definition of the warning strategy of the EUCLIDE system. The aim is to achieve the highest balance between a totally supportive and a non-disturbing system. The paper describes this design process and concentrates on the in-vehicle integration process and on the road tests with subjects.

Tilak Dutta, *Member*, *IEEE*, and Geoff R. Fernie [7] have been developed Anti-collision systems for use with powered wheelchairs in order to enable people with cognitive or physical impairments to safely operate a powered wheelchair. Anti-collision systems consist of sensors that have the ability to detect objects near the wheelchair and a computer that can stop the chair if a collision is determined to be likely. This investigation considered the suitability of using ultrasound sensors in such a system when encountering objects typically found within a home or a long-term care facility. An ultrasound sensor's ability to detect an object was dependent on the object's size, shape, specularity, reflectivity, and sound absorption characteristics.

Hai Huang and Geoff R. Fernie [8] said that the residents in long term care facilities with cognitive impairment and mobility disability need an anti-collision system on their powered wheelchairs to prevent them from causing other seniors to fall. Because of the severe consequence of falling, the detection method of the anti-collision system must be very reliable. This research evaluated an uncommon method: Laser Line Object Detection (LLOD). The LLOD system projects an invisible infrared laser line onto the ground, and reads the resulting image via a camera. By analyzing the laser line in the image, the system can identify whether objects are in the target area. The results of the evaluation experiments showed that the LLOD system can detect almost all obstacles with different orientations and materials, and produced a high detection rate on favorable flooring surfaces.

Abel Mendes and Urbano Nunes [9] addresses the 'development of an anti-collision system (ACS) based on a laser scanner', for low speed vehicles running in Cyber-cars scenarios. The ACS core is a multi-target detection and tracking system (MTDATS), which is able to classify several kinds of objects and can be easily expanded to detect new ones. The MTDATS is composed by five modules: 1) scan segmentation; 2) situation based information integration; 3) object classification using a suitable voting scheme of several object properties; 4) object tracking using a Kalman filter that takes the ohjd type to increase the tracking performance into account; *5)* and a database being tracked at each interval of data processing. For each database object, the time to collision with the vehicle is computed. The worst case time-to-collision and the correspondent predicted impact point on the vehicle, are sent to the path-following controller, which using this information provides collision avoidance behavior.

Abel Mendes, Luis Conde Bento and Urbano Nunes [10] had said that the path-tracking controller of a bi-steerable cybernetic car with an anti-collision behavior. The velocity planner and the anti-collision system are fundamental modules in the architecture. The path tracking implementation uses fuzzy logic. The smoothness of the acceleration profile was one of requirements taken into account in the controller design. The anti-collision system based on Laser Range Data consists of estimating the trajectories and behavior of surrounding objects. Simulation and experimental results are presented showing the effectiveness of the overall navigation control system.

Luigi Giubbolini [11] has developed an adequate radar technology for the detection and localization of obstacles before, behind and on the sides of a moving car is of primary importance to realize on-board devices able to perform different tasks such as parking, stop and go, and pre alarm of the frontal air-bags. In these situations, the radar must acquire the position of the obstacles located at short distances from the car. This acquisition must be carried out with high radial and angular resolution. It is for this reason that traditional anti-collision systems based on phase array antennas prove to be unsuited to perform these tasks in the short range. This prototype works in the 13.4–14 GHz frequency range at low power (16 dBm eirp) and it has been realized with microstrip technology so that thanks to its reduced size each device can be embedded easily in a bumper.

LINAC developments

Charles W. Schmidt [13] has described that the Fermilab Linac Upgrade will increase the linac energy from 201 MeV to 401.5 MeV. Seven accelerating modules, composed of 805-MHz side coupled cells, will accelerate Hydrogen-beams from 116.5 to 4015 MeV. All seven accelerating modules, each containing four sections of sixteen cells, have been connected to 12-MW power klystrons and tested to full power for a significant period. The transition section to match the beam from the 201.25-MHz drift-tube linac to the SCS, consisting of a sixteen-cell cavity and a vernier four-cell cavity, has also been tested at full power. Beam commissioning of the project will follow and normal operation is expected in a short period. In preparation for beam commissioning, studies are being done with the operating linac to characterize the beam at transition and prepare for phase, amplitude and energy measurements to commission the new linac. The past, present and future activities of the 400-MeV Upgrade will be reviewed.

Y. Wang, M. Fedurin, P. Jines, T. Miller, T. Zhao [14] stated that the 180 - 200 MeV linac is an injector of Center of Advanced Microstructures and Devices (CAMD) 1.3 or 1.5 GeV accelerator, and was configured, installed and commissioned more than 10 years ago. CAMD has pursued the upgrades *of* linac due W the bad reliability and performance of linac. In the paper, the latest operation parameters of linac are introduced, the results of recent upgrades of linac, such as the linac control system upgrade, the linac timing system upgrade, the master oscillator upgrade, and the klystron focusing power supply upgrades are presented, and the linac energy increase is discussed.

SUMMERY

From the above literature review the reference papers [2],[3] and [4] give the idea for past work in the anticollision for the medical LINAC machine. The reference papers [5],[6],[7],[8],[9],[10] and [11] give the idea for the anticollision technique used in various fields. then I have also seen some recent developments in LINAC machine some of them given in reference papers[12] and [13].
so from the above all I concluded that it will be fast, accurate, compact and low cost anticollision device if develop by the use of embedded system.

Chapter-3

Techniques and Comparison

Radio-surgery

Radio-surgery is a new technique for treating brain tumours that is available in only a few specialized neurological centers. The two main methods of carrying out radiosurgery are by gamma knife and by modified LINear ACcelerator(LINAC). Both of these procedures use a high energy dose of radiation that can be focused on a very precise point within the brain.

The Linac is a general radiotherapy device that can be used for radiosurgery. The gamma knife is a device that has been designed specifically for radiosurgery. Radiotherapy may require a number of visits over weeks or months; however, radiosurgery is completed in one visit and usually does not require an overnight stay. People are able to return to their normal routine immediately following treatment without some of the side effects of radiotherapy or open surgery. Whereas the linac uses only one beam of high energy radiation, the gamma knife uses 201 energy sources that combine to form a high energy point at the focus, each source being too weak to damage the healthy brain tissue in the path or surrounding areas. [15,16]

This approach may be suited to deep-seated tumours within the brain, such as acoustic neuromas, that may be difficult to reach by other methods without causing damage to the surrounding healthy brain tissue. Not all acoustic neuromas are suitable for treatment by radiosurgery and the best individual course of action should be discussed with consultant.

Radiotherapy

Radiotherapy is the use of x-rays and similar rays (such as electrons) to treat disease. Radiotherapy is occasionally used to treat benign tumours.Since the discovery of x-rays over one hundred years ago, radiation has been used more and more in medicine, both to help with diagnosis (by taking pictures with x-rays), and as a treatment (radiotherapy). While radiation obviously has to be used very carefully, doctors and radiographers have a lot of experience in its use in medicine. Many people with cancer will have radiotherapy as part of their treatment. This can be given either as external radiotherapy from outside the body using x-rays or from within the body as internal radiotherapy. Radiotherapy works by destroying the cancer cells in the treated area. Although normal cells are also sometimes damaged by the radiotherapy, they can repair themselves. Radiotherapy treatment can cure some cancers and can reduce the chance of a cancer coming back after surgery. It may be used to reduce cancer symptoms. Some people find that the side effects are very mild and that they just feel tired during their course of radiotherapy treatment.

Figure- 3.1 Radiotherapy destroys tumours with radiation

The effect on the tumour is to slow its growth and lengthen the time before re-growth. In some circumstances, it may cure the tumour. The treatment is painless and involves lying on a specially designed table for a few minutes.[16,21]

LINAC-Radiosurgery and Radiotherapy

LINAC is short for the term linear accelerator. Linear accelerator machines produce radiation that is referred to as high energy X-ray. A linear accelerator machine is designed to be a general purpose radiation delivery machine and in general requires modifications to enable it to be used for radiosurgery or IMRT. Often the modification is the addition of another piece of machinery.

There may be dedicated or non-dedicated LINAC machines. The dedicated type have the additional equipment to perform the higher level treatment permanently attached the radiation couch. This is the preferred method. The non-dedicated LINAC machines may be used for conventional radiation therapy in the morning and the after adding the attachment, are used for higher level treatments in the afternoon. Non-dedicated machines are unable to acquire the same degree of precision and accuracy that dedicated machine may have.

Radio surgery can be preformed with linear accelerator machines. By definition, radio surgery is a one session surgical procedure directed by a neurosurgeon and a radiation oncologist. The total procedure occurs in one day from immobilization, scanning, planning and the procedure itself. With radio surgery, the radiation dose given in one session is usually less than the total dose that would be given in radiation therapy. This is important as higher radiation to surrounding areas when a person is given a few (2-5 treatments) may result in more side effects, some of which may be permanent. More importantly, the effect on a tumor of a reduced amount of radiation with each treatment versus a very high one time dose can result in less tumor control and poorer outcomes than radio surgery. [16]

LINAC technology is most often used in multi-session treatments in order to avoid damage to healthy surrounding tissue as the total dosage is higher than with one session radio surgery but given in smaller amounts which may allow the tumor to continue growing.

Chapter-4

LINAC

4.1 Introduction

A linear accelerator (LINAC) is the device most commonly used for external beam radiation treatments for patients with cancer. The linear accelerator can also be used in stereo tactic radio surgery similar to that achieved using the gamma knife on targets within the brain. The linear accelerator can also be used to treat areas outside of the brain. It delivers a uniform dose of high-energy x-ray to the region of the patient's tumour. These x-rays can destroy the cancer cells while sparing the surrounding normal tissue.

The linear accelerator is a precise, reliable treatment instrument, with a wide range of capabilities. Strictly speaking, the term 'linear accelerator' only applies to that part of the system wherein electrons are accelerated to the required level of energy. However, in this treatment, the term is used to describe the whole system used for radiotherapy treatments.

The patient's radiation oncologist prescribes the appropriate treatment volume and dosage. The medical radiation physicist and the dosimetrist determine how to deliver the prescribed dose and calculate the amount of time it will take the accelerator to deliver that dose. Radiation therapists operate the linear accelerator and give patients their daily radiation treatments.

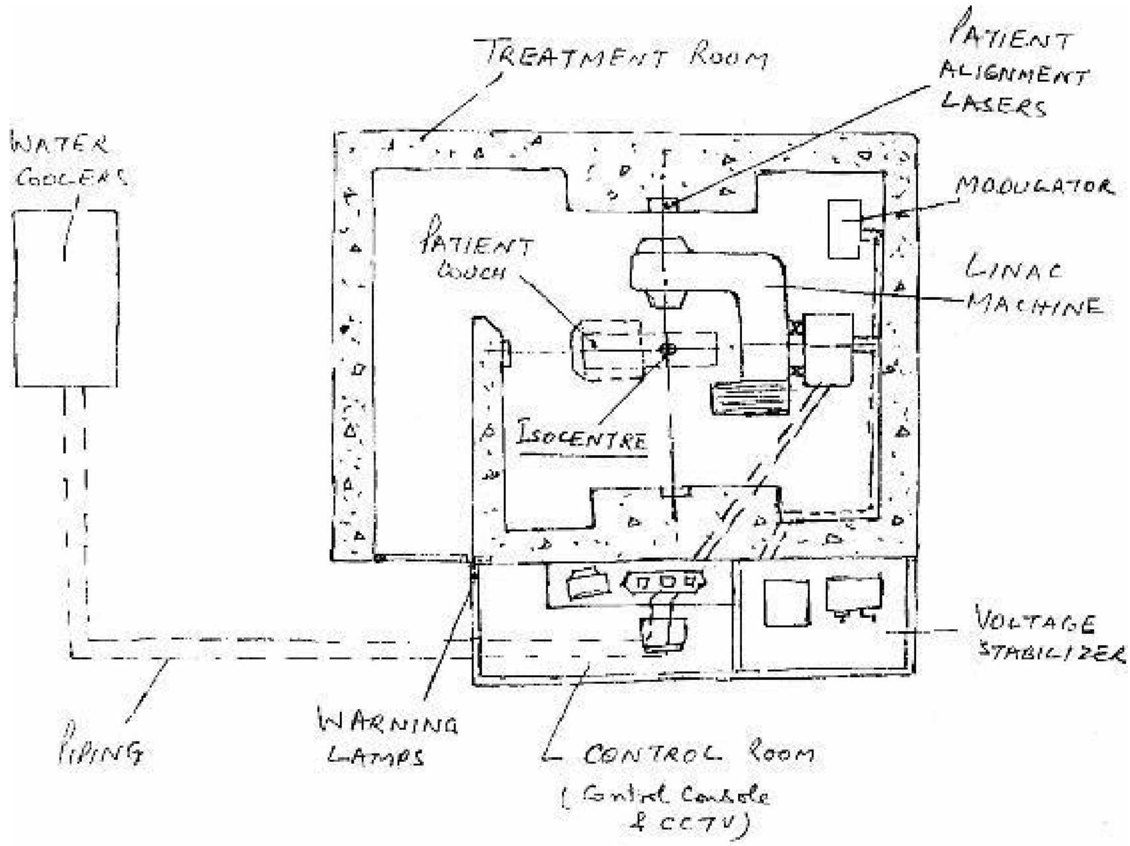


Figure - 4.1 Layout of a radiotherapy Facility (courtesy PGI/CSIO)

4.2 LINAC Equipment subsystems

The radiotherapy set-up can be broken down to following subsystems:

- LINAC handling system (Gantry system)
- Patient support system (Patient couch)
- X-Ray beam generation system
- Static patient set-up aids
- Control console
- Treatment room

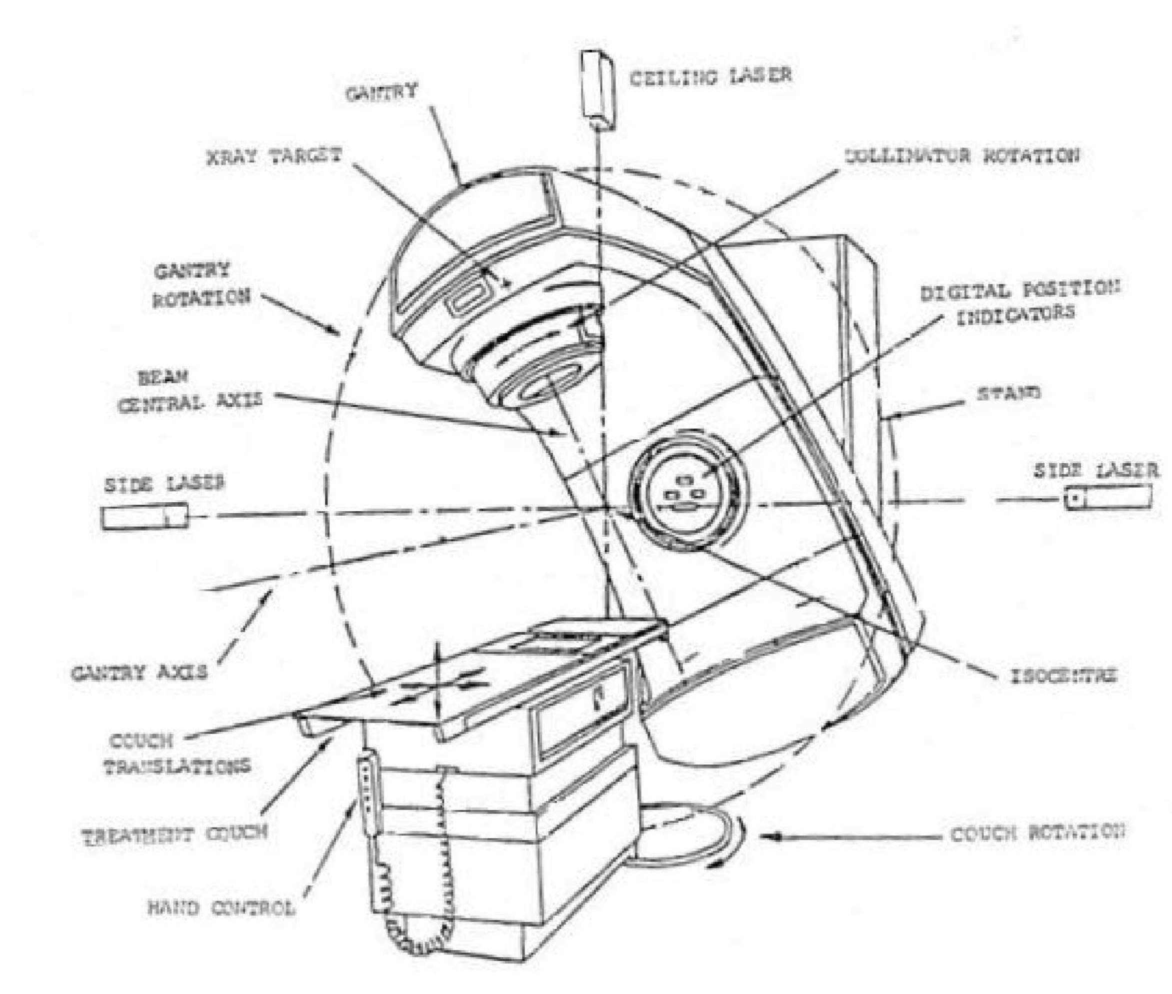


Figure -4.2 Equipment sub-system

4.3 LINAC handling system

House the LINAC X-Ray tube and associated systems required to produce the radiation beam. And to provide means for maneuvering the beam for its precise application in the desired direction. It comprises of the following modules:

4.3.1 Base frame

This is a welded girders frame, serving as a common link between the gantry system and the patient couch it is grouted in the floor in a specially prepared R.C.C. pit to ensure erection stability.

4.3.2 Stand

It supports the rotating gantry through a special bearing and houses gantry drive components, such as drive motor, chain and socket drive, angle encoder, 0 to 360^o limit system for gantry, water cooling system Freon pressurization system and electronic controls.

4.3.3 Gantry

This is a U- shaped structure and carries the LINAC tube with shielding, primary and secondary collimators, microwave system components and water cooling piping arrangement. All are mounted on the horizontal arm of the gantry which rotates about the horizontal axis. The gantry is supported on a vertical stand which is firmly fixed to a frame Embedded in the floor. It is mounted to the stand with a hollow- bore large size special bearing.

Figure -4.3 Setup for test. Gantry is currently at 0°

The gantry can rotate through full revolution about the bearing axis (horizontal). Also, it is balanced by a counter weight to enable easy rotation. Gantry rotation speed is electronically controlled. A DC motor may be used whose speed can be controlled with a thyristor-based speed controller. Also, the gantry angle can be seen on an electronic display. The gantry speed is continuously variable from 0.1 to 1 rpm. The gantry rotates through total useful range of 360°, in both clockwise and counter-clockwise directions.[1,18]

Figure -4.4 Gantry Rotation

4.4 Patient support system (Patient Couch)

This unit provides precision movements to the patient for accurate set up with respect to the beam axis. The motion of the treatment couch is accomplished through controls located on the side of the couch or through a device called a pendant. The pendant is either suspended from the ceiling or attached by a flexible cord to the treatment couch. The treatment couch should have an adequate range of travel, laterally, longitudinally, and vertically. Motions provided are (PGI/CSIO Chandigarh LINAC machine):

1. longitudinal 125 cms
   Slow and fast speeds
2. Transverse ±25 cms

		Slow and fast speeds
3.	Vertical	100 cms (60cms to 160 cms) (Above floor level) Slow and fast speeds
4.	Iso-centre rotation	$\pm 90^o$ Slow and fast speeds
5.	Couch-top rotation	360^o about a central pivot

Sometimes, to accommodate an exceptionally tall patient, a head extension board may be added to the couch to increase its length. Since it is much easier to rotate the treatment couch than to try to re-adjust the angle at which the patient is lying on the couch, a few degrees of rotation is usually adequate to assure that the patient is accurately and appropriately aligned. [19]

Lasers are used to project a line on the patient along the length of couch. Alignment of the patient by this line will assure that the patient is perpendicular to the plane of the rotation of the unit, a very critical alignment for arc therapy and multiple field isocentric treatments.

All couch motions are motorized and motor speed controls are electronic. Mechanisms of patient couch utilize:

- Cross roller bearing for turn table center.
- Linear bearing for all slides.
- Permanent magnet DC geared reversible motors with speed controllers.
- Rack and Pinion/ Timing belt pulley drivers.

In the modem machines, the patient set-up is automated under computer control. Since the treatment radiation times with modem accelerators are very short, typically less than 1 or 2 minutes, improvements in the operational aspects of the set-up procedure will permit the accelerator to treat more patients and thus make the treatments more cost-effective. [16,18]

4.5 X-ray beam generation system

The system modules are in following sequence.

4.5.1 Mains stabilizer

The machine on 3-phase mains supply, For trouble free operation a constant voltage supply of 15 KVA per phase is needed.

4.5.2 LINAC Tube

The LINAC Tube is based on the Standing Wave principle, where acceleration of electrons takes place in the main cavities and microwave power is fed from one main cavity to another through side cavities.

4.5.3 The Accelerator

The heart of the radiotherapy linear accelerator machine is the accelerator. The accelerator is a sealed off vacuum tight tube. It has an electron gun, accelerating cavity, RF Window for microwave power input and target. The vacuum inside is maintained below 10^{-8} mm of Hg. The accelerated electrons strike the target resulting in the production of X-rays. All accelerators have four major components: the modulator, electron gun, Microwave source, and accelerator guide which are connected as shown in Fig.-4.5. The electron accelerator is a wave guide structure which is energized at microwave frequency, most commonly at 3000 MHz. The microwave radiation is supplied in short pulses, a few microseconds long.

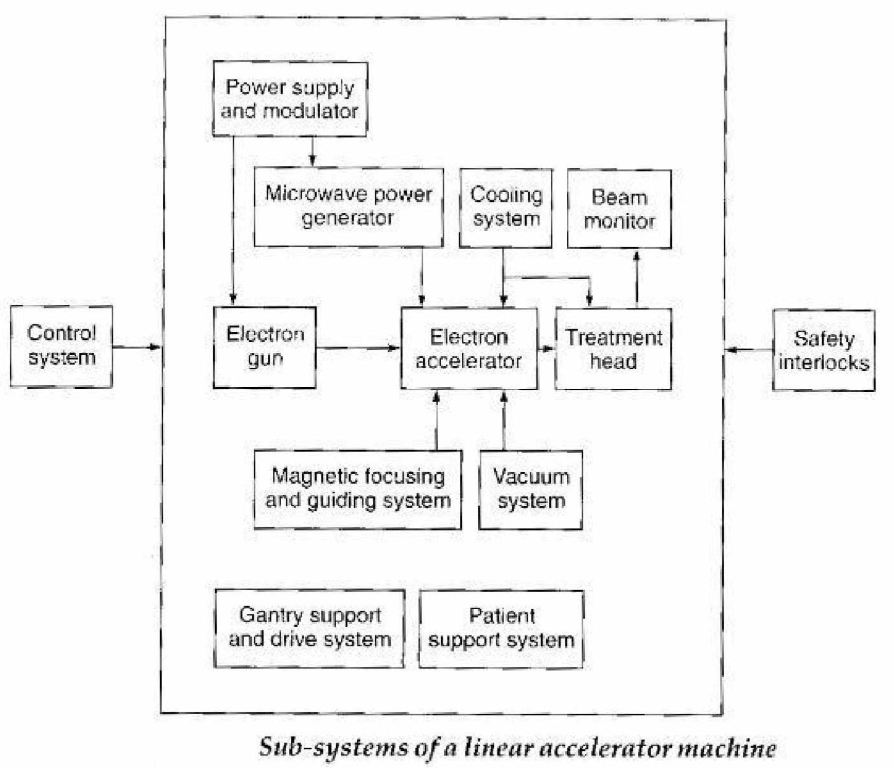


Figure -4.5 Block Diagram of Linac Unit

(i) H.V. Modulator

The primary function of the modulator circuit is to supply high voltage pulses to the microwave generator. It steps up the input mains three-phase power supply (380V -440V) to about 50 kV prior to its rectification to DC. Specialized circuitry within the modulator produces high voltage pulses at the rate of a few 100 pulses per second. The modulator may be located either in the gantry or the gantry supporting stand, or in a separate cabinet that can be located at some distance from the accelerator. Electrical connections to the electron gun and the RF power source are made through high-voltage cables.

(ii)Electron Gun

The electron gun is pulsed by the modulator and injects pulses of electrons of a few micro-seconds duration into the accelerator guide at energies of about 15-40 keV. The electrons are subsequently accelerated in the accelerator guide to the required energy level. The electron gun can either be a diode device with direct or indirect heating of the cathode, or a triode device in which the grid can be used to obtain control of the injected electron current in the electron mode.

(iii)RF Power Source

The RF power source is either a magnetron or a klystron. Klystrons are generally used in high-energy accelerators and magnetrons in low- or medium-energy accelerators. Tube Linac has its own RF system that drives their appropriate cavity fields to the increased level and phase necessary for the particle to gain in energy. This power is sent via a coaxial transmission line.

(iv)Accelerator Wave Guide

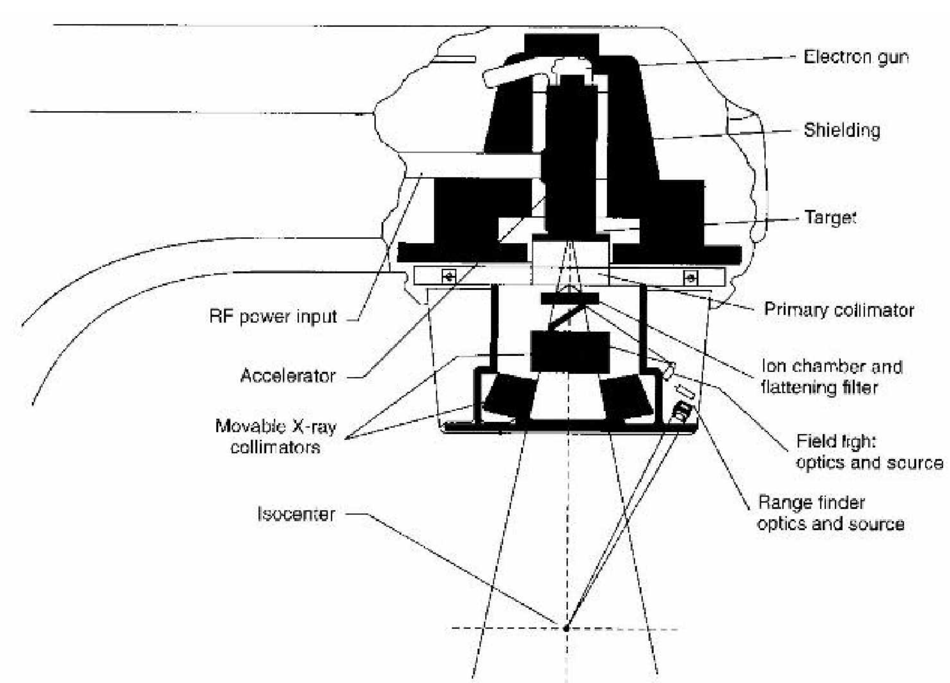
A charged particle traveling along the axis of a series of conducting tubes which are connected to an alternating voltage gets accelerated and acquires energy as it passes through each gap between the tubes. A system using a radio frequency supply was not found to be practical because the high velocity attained by the particles would require very long flight tubes when radio frequency was used. However, at microwave frequencies, it became possible to accelerate electrons to energies of several million electron volts.In practice, the accelerator structure or wave guide is made up of a number of specially shaped, copper microwave resonant cavities that have been brazed together to form a single structure. The length of the accelerator wave guide will vary from about 30 cm to 2.5 m. depending on the final electron energy and the type of structure utilized.

Vaccume conditions need to be created in the accelerator wave guide so that the electrons being accelerated should not be deflected by collisions with gas atoms. For this purpose, an ion pump is used which has a working range of 10^{-3} to 10 torr. [20]

4.5.4 Shields and Collimator

The collimator jaws should typically absorb 99% or more of the radiation and the opening should be variable to 40 x 40 cm at the isocentre to facilitate large field treatments. The collimator jaws should be able to close completely for certain quality control procedures, but need only be adjustable to an opening as small as 2 x 2 cm for most clinical use. The entire collimator assembly can be rotated about an axis that passes through the centre of the treatment field and the isocentre, the point in space where the gantry axis of the accelerator intersects the collimator axis of rotation. The ability to rotate the collimator allows the treatment field to be rotated, if required. [18]

The collimator assembly also contains a light source that projects a light field onto the patient to define the entry position of the radiation field during the setup of the patient. An optical range finder projects the distance from the target to the patient surface. All linear accelerators manufactured today are isocentric treatment units. The mechanical stability of the gantry structure and radiation head components during rotation generally assures that the beam axis passes within the 2 mm of this isocentre point. This means that the tumour may be centered at the isocentre and the treatment unit rotated without requiring that the patient be repositioned. Thus, multiple fixed fields can be delivered with great accuracy and efficiency. [1]



Schematic of accelerator and collimator sub-systems

Figure -4.6

The Concept of Isocentre-The three entities involved have to be interrelated with each other as shown in Fig.-4.7. This is best done by establishing a point in space called the Isocentre. Normally it is a point 100 centimeters from the X-Ray source and about 130centimeters from floor level. All system of machine and the patient must not deviate more than ±1mm from this point this is the most critical requirement.

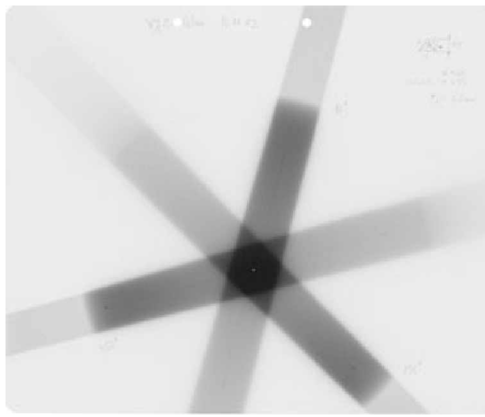


Figure -4.7 Isocentre

4.5.5 Cooling System

Because of resistive losses in the guide walls and because some electrons may strike the structure, their accelerator guide will heat up in operation. Consequently, thermal expansion may result in significant changes in dimensions. A water cooling system for-the wave guide is provided in the form of a water jacket through which temperature-controlled water is circulated at a predetermined rate. The X-ray target also needs to be cooled. A cooling system based on circulating water and operated using a thermostat is generally employed. A closed loop distilled water cooling system is incorporated to control the temperature of

- LINAC Cavities
- Magnetron
- Tungsten Target

4.6 Static patient set-up aids

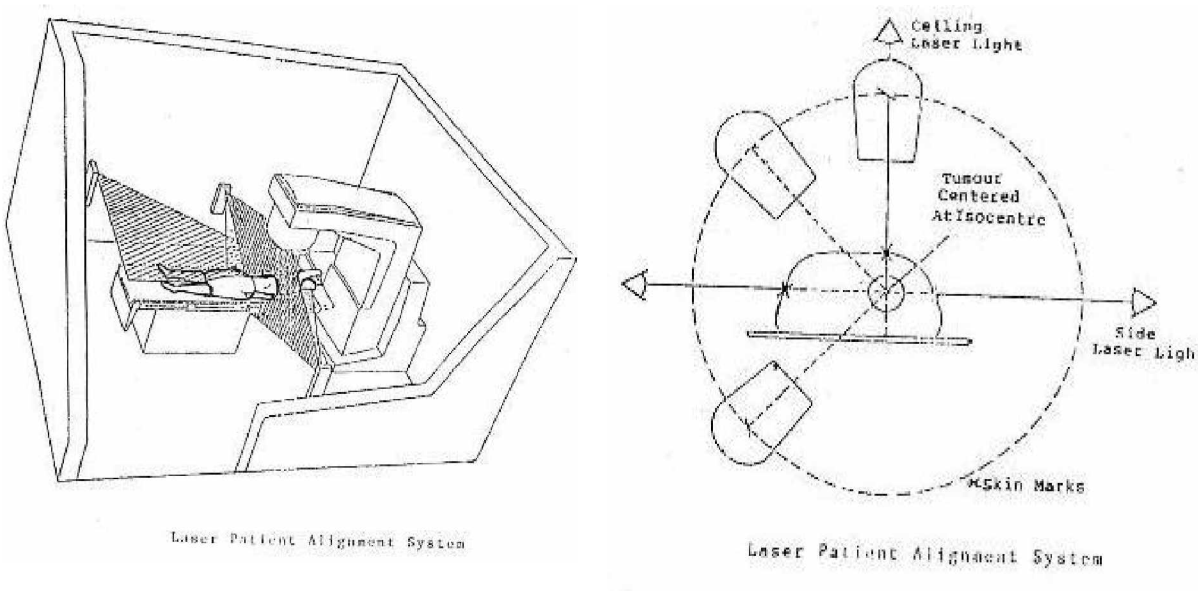


Figure -4.8 Set –up Aids

4.6.1 Field Light Assembly

This system is used for the simulation of X-ray field. It consists of a Lamp, a Condenser lens, Reflector and optical cross- hair. The light beam is adjusted such that is coincides with the X-ray beam.

4.6.2 Optical Range Finder

The optical range finder is used to determine SSD (Source to Skin Distance) within the range of 75 to 130 cms. The range scale is projected on the patient's skin. As the patient couch moves vertically, the SSD is displayed.

4.6.3 Dose Rate

While beam energy is generally the prime consideration in selecting a treatment unit, the dose rate is also important. Dose rates should be at least 200 cGy /min for all energies. Higher dose rates are often desirable for treatments at extended distances or to treat children or uncooperative or infirm patients quickly. The higher the dose rate, the shorter the treatment time, and the smaller the probability of patient motion during treatment.

4.7 Control Console

The machine is controlled by a control console located outside the treatment room. The design of control consol simplifies daily operation of the machine. While different manufacturers will incorporate different features in their control systems, all consoles enable the operation of the unit, allow selection of the dose to be given for the treatment, and contain interlock circuitry designed to protect both the patient and the treatment unit. It has following provisions:

Indication/ panel meters for Integrated Dose, Dose rate, Treatment time, PFN voltage, Magnetron frequency, Gantry speed, AFC.

Setting Switches for Dose rate, Integrated Dose, Treatment time, Gantry speed.

Interlocks for Vacuum, High Voltage Power Supply, current, Water Temperature etc. The interlocks shut the machine off in the event of any fault.

Besides turning the radiation on and off, some control consoles permit remote mechanical movement of the linear accelerator. In addition to adjusting field size from the control console, it is often desirable to be able to adjust other mechanical parameters without having to re-enter the treatment room.

The machine interlock system is designed to promote safety during routine use of the equipment. Interlocks are designed to shut the machine off in the event of malfunctions in the cooling system, vacuum system, modulator, high voltage power supply, line voltage or in certain other important components of the machine. The machine is interlocked such that in the fixed beam treatment mode, motion of any of the accelerator parameters (gantry, collimator, field size or treatment couch) will stop treatment. In arc therapy, an interlock to detect the motion of any of the above accelerator parameters except for gantry rotation is designed to stop irradiation. In addition, the circuitry of the machine allows inclusion, by the user, of external interlocks such as door switches, emergency shutoffs in the treatment room, and warning lights.

4.8 Treatment Room

This is specially constructed room with extra thick RCC walls and roof with steel shuttering of special pattern for strength. The Concrete has density of $2.35 Gm/cm^3$. Following provisions are kept during its construction:

- Recesses in walls for laser systems for patient alignment.
- Ceiling hooks of steel for Installation of heavy structural members.
- Ducts for air conditioning.
- Electric conduits for light points CCTV camera, warning lights, etc.
- Ducts for cooling water pipes.

The design of room has to be certified by the atomic energy regulatory authorities regarding safety under radiation.

4.9 Working

The linear accelerator uses microwave technology (similar to that used for radar) to accelerate electrons in a part of the accelerator called the "wave guide", then allows these electrons to collide with a heavy metal target. As a result of the collisions, high-energy x-rays are scattered from the target. A portion of these x-rays is collected and then shaped to form a beam that matches the patient's tumor. The beam comes out of a part of the accelerator called a gantry, which rotates around the patient. The patient lies on a moveable treatment couch and lasers are used to make sure the patient is in the proper position. Radiation can be delivered to the tumor from any angle by rotating the gantry and moving the treatment couch.

4.10 Safety

Patient safety is very important. During treatment the radiation therapist continuously watches the patient through a closed-circuit television monitor. There is also a microphone in the treatment room so that the patient can speak to the therapist if needed. Port films (x-rays taken with the treatment beam) are checked regularly to make sure that the beam position doesn't vary from the original plan.

The linear accelerator sits in a room with lead and concrete walls so that the high-energy x-rays do not escape. The radiation therapist must turn on the accelerator from outside the treatment room. Because the accelerator only gives off radiation when it is actually turned on, the risk of accidental exposure is extremely low. Indeed, pregnant women are allowed to operate linear accelerators.

Modern radiation machines have internal checking systems to provide further safety so that the machine will not turn on until all the treatment requirements prescribed by physician are perfect. When all the checks match and are perfect, the machine will turn on to give patient treatment. Quality control of the linear accelerator is also very important. There are several systems built into the accelerator so that it won't deliver a higher dose than the radiation oncologist prescribed. Each morning before any patients are treated, the radiation therapist uses a piece of equipment called a "tracker" to make sure that the radiation intensity is uniform across the beam. In addition, the radiation physicist makes more detailed weekly and monthly checks of the accelerator beam.

4.11 General side effects of Radio treatment

While external radiotherapy can destroy cancer cells, it can also have an effect on some of the surrounding normal cells. The side effects that may occur are described in this section. It is important to remember that no person will have more than a few of them, and for many people they may be very mild. Most side effects of radiotherapy disappear gradually once the course of treatment is over. However, the side effects may continue for a few weeks.

Tiredness: You may find that patient feel very tired during radiotherapy. This can often be made worse by having to travel to treatment each day.

Eating and drinking: As always during treatment of any kind, it is important to maintain a healthy diet and drink plenty of fluids. It may be easier to have small snacks throughout the day rather than large meals.

Changes in patient blood: Radiotherapy to some parts of the body can sometimes affect the bone marrow, which produces the different types of blood cells. It may also need to have a blood transfusion.

Skin care: Some people develop a skin reaction, similar to sunburn, while having external radiotherapy. This normally happens after 3–4 weeks. People with pale skin may find that the skin in the treatment area becomes red and sore or itchy. People with darker skin may find that their skin becomes darker and can have a blue or black tinge. The amount of the reaction depends on the area being treated and the individual person's skin.

Avoiding the sun: The treated area is so sensitive it should not be exposed to the sun or cold winds. If the patient is having radiotherapy to the head or neck, they have to try wearing a silk or cotton scarf when they go outside.

Clothing: Loose-fitting clothes, preferably in natural fibers rather than man-made materials, are more comfortable and less irritating to the skin. If patient having radiotherapy to neck, avoid tight collars and ties.

Smoking: Research has shown that it may make the radiotherapy more effective as well as reducing the side effects. It will also improve patient’s general health and reduce risk of developing other cancers.

Relaxation: Deep relaxation is a skill which can be learned. It can be used to:

- release muscle tension
- relieve stress
- reduce tiredness and pain
- improve sleep and peace of mind
- regain control of emotions

Chapter-5

Hardware

The development of hardware is carried out with the help of microcontroller 8051 , intelligent LCD module for display, stepper motors and for all these the power supply. The basic block diagram is shown below; then the circuit diagram of the hardware shown in which connections are shown. the detail of each component given there after.

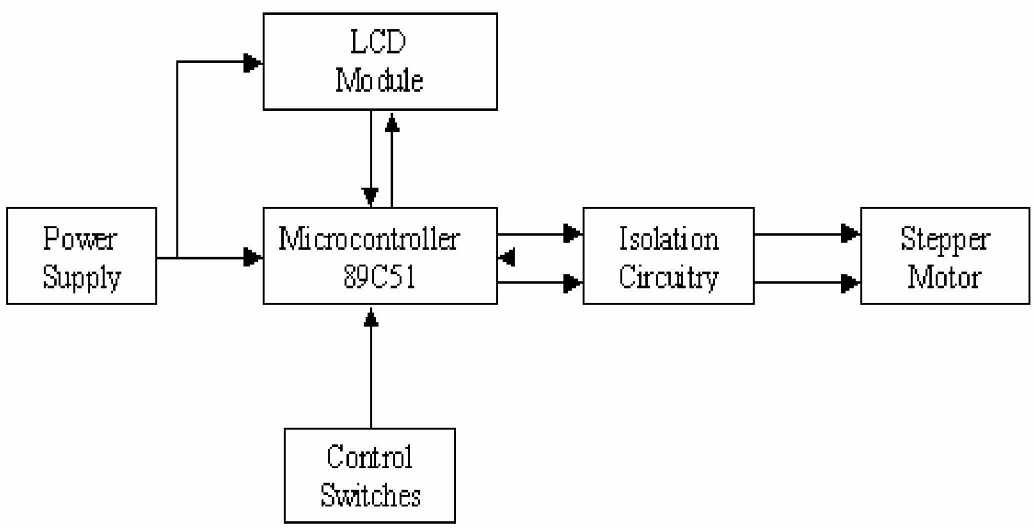


Figure -5.1   Block Diagram

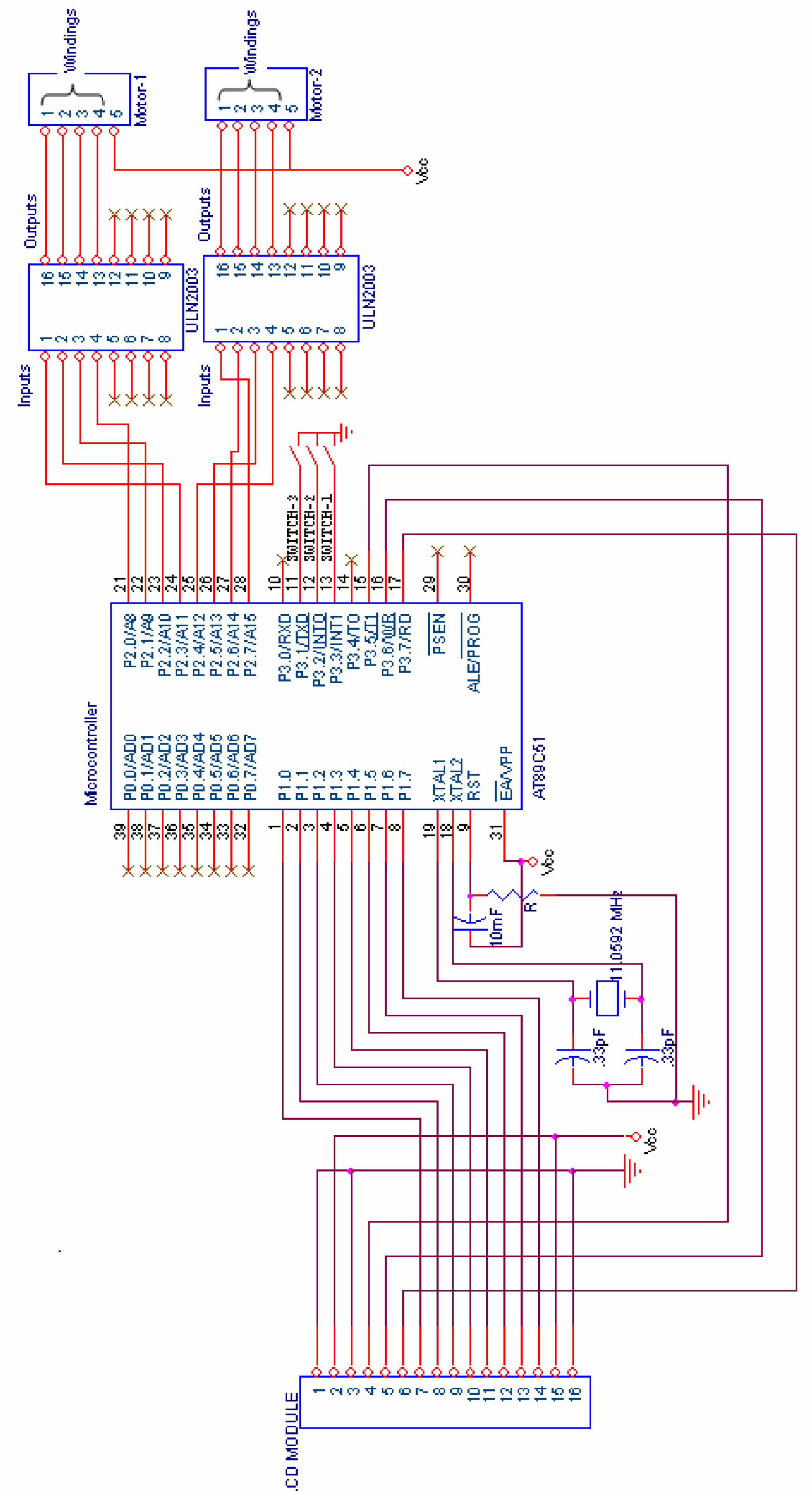


Fig-5.2 Circuit Diagram

5.1 Microcontroller AT89C51

The AT89C51 is a low power, high performance CMOS 8-bit microcontroller with 4Kbytes of Flash programmable and erasable read only memory (PEROM). This device is compatible with the industry standard 8051 instruction set and pin-out. The on-chip Flash allows the program memory to be quickly reprogrammed using a nonvolatile memory programmer such as the PG302 (with the ADT87 adapter). By combining an industry standard 8-bit CPU with Flash on a monolithic chip, the AT89C51 is a powerful microcomputer which provides a highly flexible and cost effective solution to many embedded control applications.

Figure -5.3 AT89C51 Microcontroller Chip

5.1.1 Microprocessor Vs Microcontroller

A microcontroller is a true computer on a chip. The design incorporates all the features found in the microprocessor CPU namely:

- Arithmetic and Logic Unit (ALU)
- Program Counter
- Stack Pointer
- Working Registers
- Timing circuits
- Interrupt Circuits

With the added features:

- Read Only Memory (ROM)
- Random Access Memory (RAM)
- Parallel I/O
- Serial I/O
- Counters and clock circuits

Thus the microprocessor must have many additional parts to be operational as a computer whereas microcontroller requires no additional external digital parts. The prime use of microprocessor is to read data, perform extensive calculations on that data and store them in the mass storage device or display it. The prime functions of microcontroller are to read data, perform limited calculations on it, control its environment based on these data. Thus the microprocessor is said to be general-purpose digital computers whereas the microcontroller are intend to be special purpose digital controller. [22,23]

5.1.2 Choosing a Microcontroller

There are four major 8-bit microcontrollers. They are Motorola's 6811, Intel's 8051, Zilog's Z8, and PIC 16 X from microchip technology. Each of the above microcontrollers has a unique instruction set and register set therefore they are not compatible with each other. Programs written for one will not run on the others. There also exist 16-bit and 32-bit microcontrollers, manufactured by different chip manufacturers. With all these different microcontrollers, what criteria do designers consider in choosing one.

Three main points are as follows:

(1) Meeting the computing needs of the tasks at hand efficiently and cost effectively.

(2) Availability of software development tools such as compilers, assemblers and debuggers.

(3) Wide availability and reliable sources of microcontrollers.

5.1.3 AT89C51 features

(a)Hardware features

~ 4 Kbytes of Flash

~ 128 bytes of RAM

~ 32 I/O lines

~ two16-bit timer/counters

~ five vector, two-level interrupt architecture

~ full duplex serial port

~ on chip oscillator and clock circuitry

(b)Software features

~bit manipulations

~single instruction manipulation

~separate program and data memory

~4 bank of temporary registers

~direct, indirect, register and relative addressing.

In addition, the 89c51 is designed with static logic for operation down to zero frequency and supports two software selectable power saving modes. The Idle Mode stops the CPU while allowing the RAM, timer/counters, serial port and interrupt system to continue functioning. The Power down Mode saves the RAM contents but freezes the oscillator disabling all other chip functions until the next hardware reset.

The Atmel Flash devices are ideal for developing, since they can be reprogrammed easy and fast. Atmel offers a broad range of microcontrollers based on the 8051 architecture, with on-chip Flash program memory.

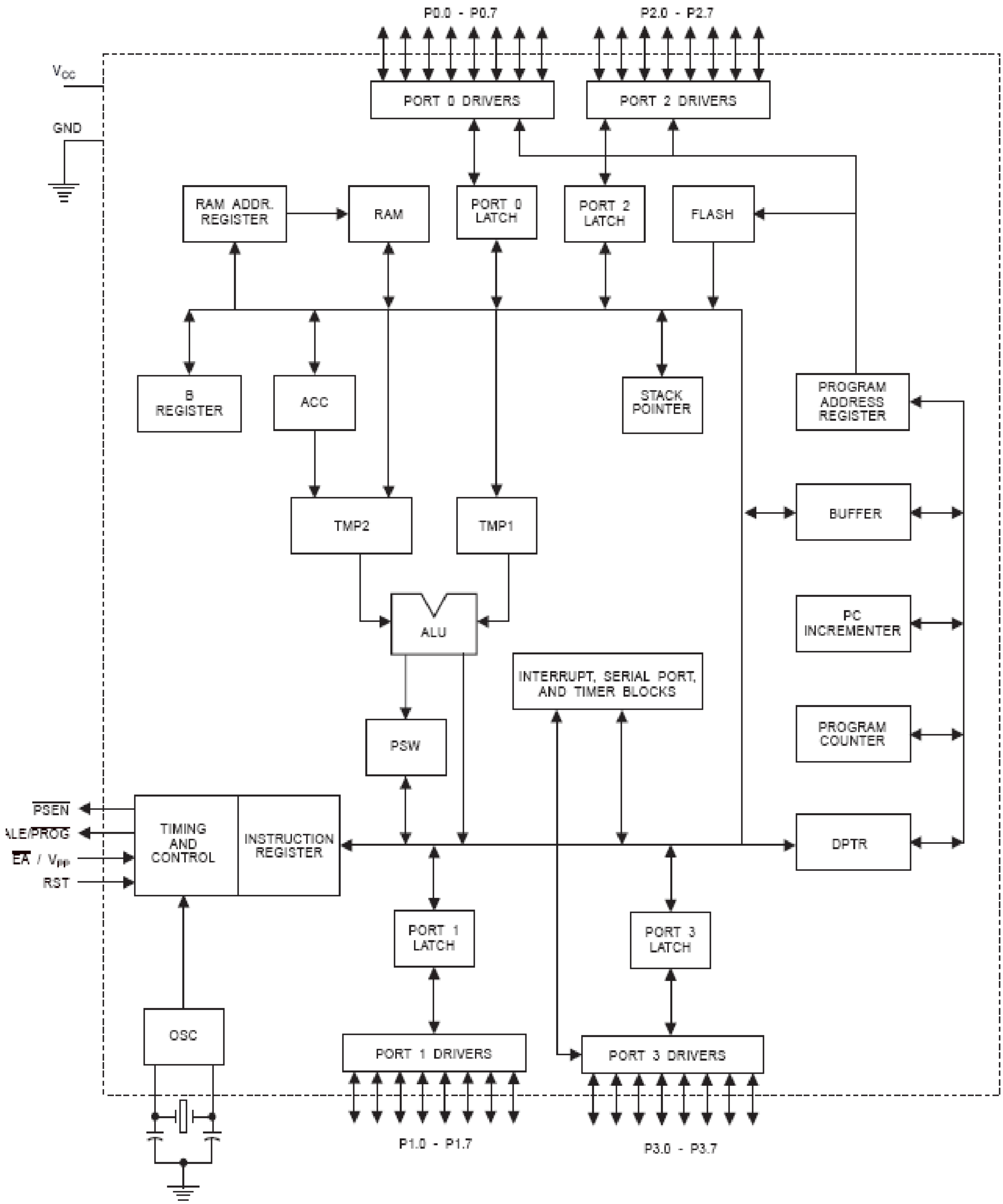


Figure -5.4 Internal Architecture of AT89C51

5.1.4 Pin Configurations

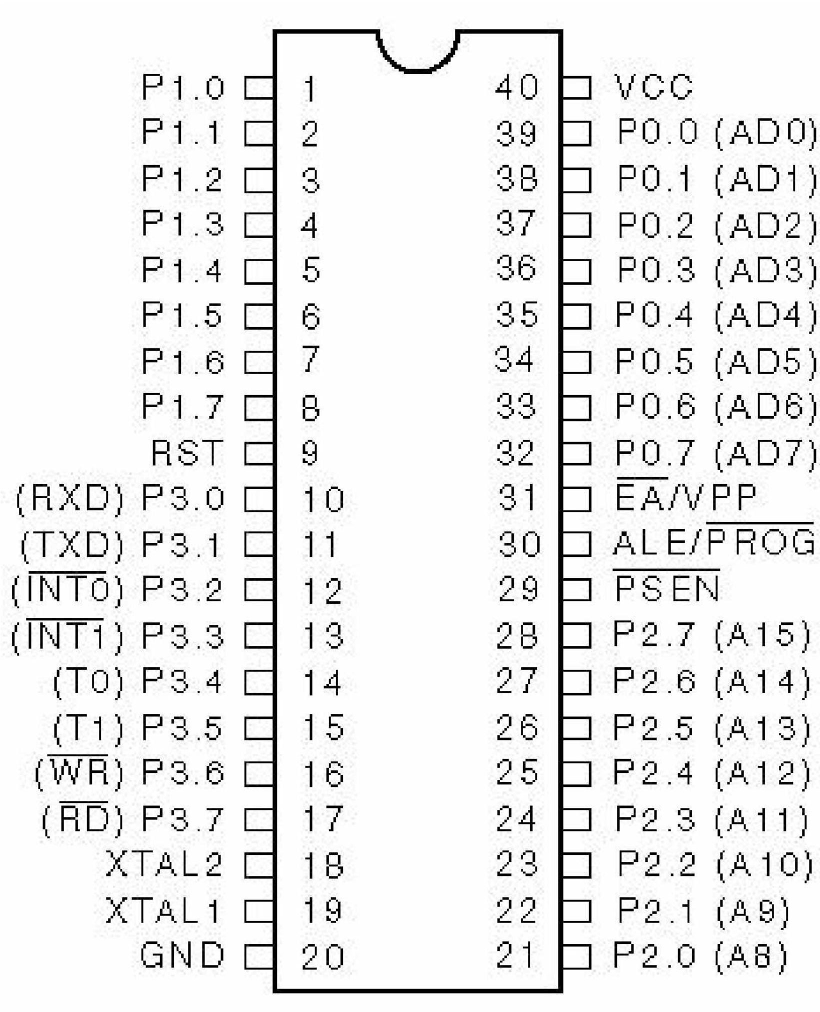


Figure -5.5 Pin Configuration of AT89C51

VCC

Pin 40 provides supply voltage to chip of +5v d.c.

GND

Pin 20 is Ground.

I/O Ports

Ports 0, 1, 2 and 3 are an 8-bit open-drain bi-directional I/O port. As an output port, each pin can sink eight TTL inputs. When 1s are written to port 0 pins, the pins can be used as high impedance inputs. Port may also be configured to be the multiplexed low order address/data bus during accesses to external program and data memory. In this mode Port has internal pull-ups. A port also receives the code bytes during Flash programming, and outputs the code bytes during program verification. External pull-ups are required during program verification. Port 3 also serves the functions of various special features of the AT89C51 as listed below:

Port Pin	Alternate Functions
P3.0	RXD (serial input port)
P3.1	TXD (serial output port)
P3.2	$\overline{\text{INT0}}$ (external interrupt 0)
P3.3	$\overline{\text{INT1}}$ (external interrupt 1)
P3.4	T0 (timer 0 external input)
P3.5	T1 (timer 1 external input)
P3.6	$\overline{\text{WR}}$ (external data memory write strobe)
P3.7	$\overline{\text{RD}}$ (external data memory read strobe)

Table-5.1

RST

Reset input. A high on this pin for two machine cycles while the oscillator is running resets the device.

ALE/PROG

Address Latch Enable output pulse for latching the low byte of the address during accesses to external memory. This pin is also the program pulse input (PROG) during Flash programming.

In normal operation ALE is emitted at a constant rate of 1/6 the oscillator frequency, and may be used for external timing or clocking purposes. Note, however, that one ALE pulse is skipped during each access to external Data Memory. If desired, ALE operation can be disabled by setting bit 0 of SFR location 8EH. With the bit set, ALE is active only during a MOVX or MOVC instruction. Otherwise, the pin is weakly pulled high. Setting the ALE-disable bit has no effect if the microcontroller is in external execution mode.

PSEN

Program Store Enable is the read strobe to external program memory. When the AT89C51 is executing code from external program memory, PSEN is activated twice each machine cycle, except that two PSEN activations are skipped during each access to external data memory.

EA/VPP

External Access Enable (EA) must be strapped to GND in order to enable the device to fetch code from external program memory locations starting at 0000H up to FFFFH. Note, however, that if lock bit 1 is programmed, EA will be internally latched on reset. EA should be strapped to VCC for internal program executions. This pin also receives the 12-volt programming enable voltage (VPP) during Flash programming, for parts that require 12-volt VPP.

XTAL1

Input to the inverting oscillator amplifier and input to the internal clock operating circuit.

XTAL2

Output from the inverting oscillator amplifier. [22,23,24]

5.1.5 Oscillator Circuitry

XTAL1 and XTAL2 are the input and output, respectively, of an inverting amplifier which can be configured for use as an on-chip oscillator, as shown in Figure below. Either a quartz crystal or ceramic resonator may be used. To drive the device from an external clock source, XTAL2 should be left unconnected while XTAL1 is driven as shown in Figure 5.7.

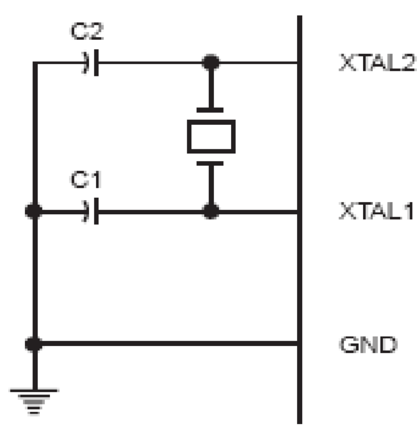


Figure -5.6 Oscillator Connections

5.1.6 Reset ckt

Reset circuit is made of capacitor and resistor. It is called as power on reset which is connected to the Pin No. 9 or reset pin. It makes the 89C51 micro controller to get reset when power is turned.

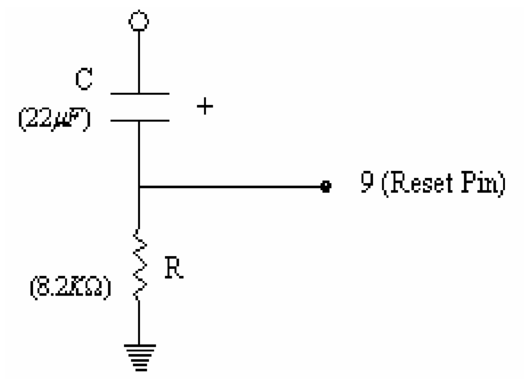


Figure -5.7 Reset Circuit

5.2 LCD Module

5.2.1 Terminal Functions

Pin No.	Symbol	Level	Function
1	Vss	-	Ground for LCD
2	VDD	-	Power Supply for LCD (+5V)
3	VO	-	Power Supply for LCD
4	RS	H/L	Register Selection H: Display Data L: Instruction Code
5	R/W	H/L	Read/Write Selection H: Read Operation L: Write Operation
6	E	H,H→L	Enable Signal. Read data when E is "H", write data at the falling edge of E.
7	DB0	H/L	In 8-bit mode, used as low order bi-directional data bus. In 4-bit mode, open these terminals.
8	DB1	H/L	
9	DB2	H/L	
10	DB3	H/L	
11	DB4	H/L	In 8-bit mode, used as high order bi-directional data bus. In 4-bit mode, used as both high and low order data bus.
12	DB5	H/L	
13	DB6	H/L	
14	DB7	H/L	
15	LEDA	--	Power supply for Backlight
16	LEDK	--	Ground for Backlight

Table-5.2 LCD Module Terminal Functions.

5.2.2 LCD Command Code

Code (HEX)	Command to LCD Instruction Register
1	Clear the display screen
2	Return home
4	Decrement cursor(shift cursor to left)
6	Increment cursor(shift cursor to right)
7	Shift display right
8	Shift display left
9	Display off, cursor off
A	Display off, cursor on
C	Display on, cursor off
E	Display on, cursor blinking
F	Display on, cursor blinking
10	Shift cursor position to left
14	Shift cursor position to right
18	Shift the entire display to left
1C	Shift the entire display to right
80	Force cursor to the beginning of 1^{st} line
C0	Force cursor to the beginning of 2nd line
38	2 line and 5×7 matrix

Table-5.3 LCD Command Code

5.3 Interfacing of Microcontroller with LCD

2 lines, 5×7 dots/char LCD display is used to display the value of current temperature and its changes with respect to normalized value. The LCD display is connected to port 1 of the µc and Register select (RS), read/write (R/W), and enable (E) are connected to port pin P3.5 to P3.7.The LCD display used is 16×2 line. V_{CC} pin is connected to +5v and V_{SS} is connected to gnd. Supply to V_{EE} pin is varied using a 10k pot to control contrast as but in the circuit we have it ground to achieve maximum contrast. [22,23,25]

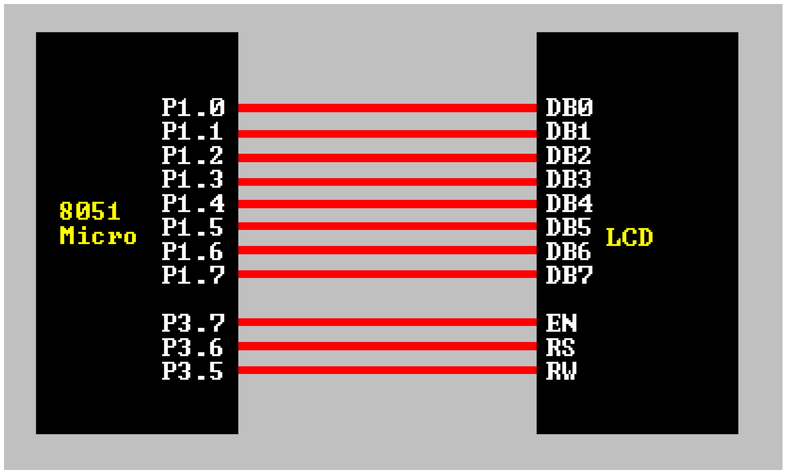


Figure -5.8 Interfacing of microcontroller with LCD

5.4 Power supply

The first block of every circuit is power supply unit. It is the most essential part of a circuit to run its constituent IC's. These ICs can run only on D.C. power. Hence, the required D.C. supply has to be generated. The main parts of power supply unit and their function are as follows.

5.5.1 Transformer

The function of the transformer is to step down the voltage level from the available A.C. 220V to the desired voltage. The rating of the transformer depends upon the requirements of the IC's in the circuit. A 9-0-9 transformer is used. The secondary has centre tapping which forms the neutral terminal.

5.5.2 Full wave Center Tap Rectifier

The function of the rectifier is to convert the alternating voltage signal in to unidirectional one. This function is provided by semiconductor diode connected to bridge configuration. Diode IN4007would be used for the rectifier.

5.5.3 Ripple rejection

The output of the diode is unidirectional but pulsating. A 1000 μf capacitor is used for ripple rejection.

5.5.4 Regulation

To obtain a constant voltage specific IC's are used as voltage regulator. LM7805 is used to obtain a +5v supply. This IC has three terminals, an input, an output and a ground terminal. [26]

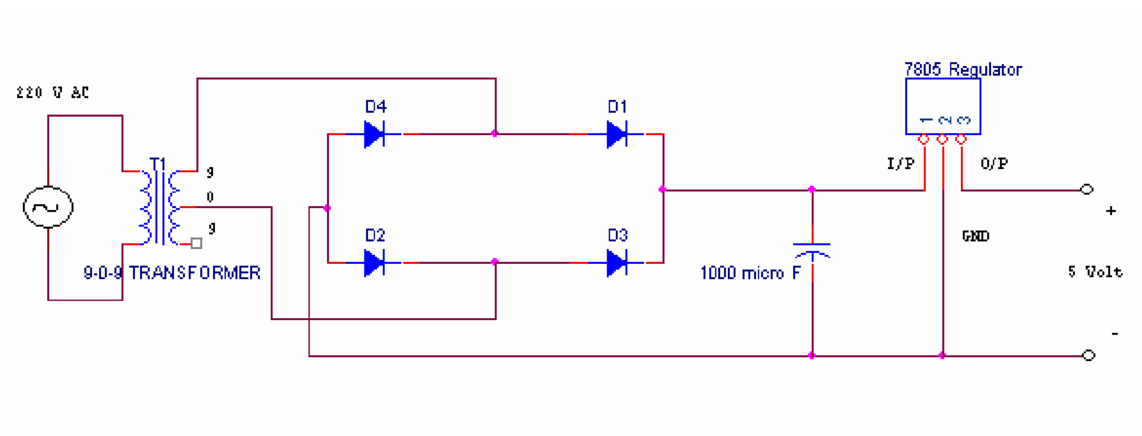


Figure -5.9 Power Supply Circuit

5.5 Stepper Motor

5.5.1 Introduction

A step motor is a type of motor that converts electrical energy to mechanical energy via the principles of electromagnetism. Also known as steppers, such motors were used as early as the 1920s. Their use has skyrocketed with the popularity of embedded systems, including printers, disk drives, toys, windshield wipers, vibrating pagers, robotic arms, and video cameras.

Stepping motors come in two varieties, permanent magnet and variable reluctance (there are also hybrid motors, which are indistinguishable from permanent magnet motors from the controller's point of view).Permanent magnet motors tend to "cog" as we twist the rotor with our fingers, while variable reluctance motors almost spin freely (although they may cog slightly because of residual magnetization in the rotor). Variable reluctance motors usually have three (sometimes four) windings, with a common return, while permanent magnet motors usually have two independent windings, with or without center taps. Center-tapped windings are used in Unipolar permanent magnet motors.

Stepping motors come in a wide range of angular resolution. The coarsest motors typically turn 90 degrees per step, while high resolution permanent magnet motors are commonly able to handle 1.8 or even 0.72 degrees per step. With an appropriate controller, most permanent magnet and hybrid motors can be run in half-steps, and some controllers can handle smaller fractional steps or micro steps.

For both permanent magnet and variable reluctance stepping motors, if just one winding of the motor is energized, the rotor (under no load) will snap to a fixed angle and then hold that angle until the torque exceeds the holding torque of the motor, at which point, the rotor will turn, trying to hold at each successive equilibrium point. [27]

5.5.2 Unipolar Motors

Unipolar stepping motors, both Permanent magnet and hybrid stepping motors with 5 or 6 wires are usually wired as shown in the schematic in Figure-5.10 , with a center tap on each of two windings. In use, the center taps of the windings are typically wired to the positive supply, and the two ends of each winding are alternately grounded to reverse the direction of the field provided by that winding.

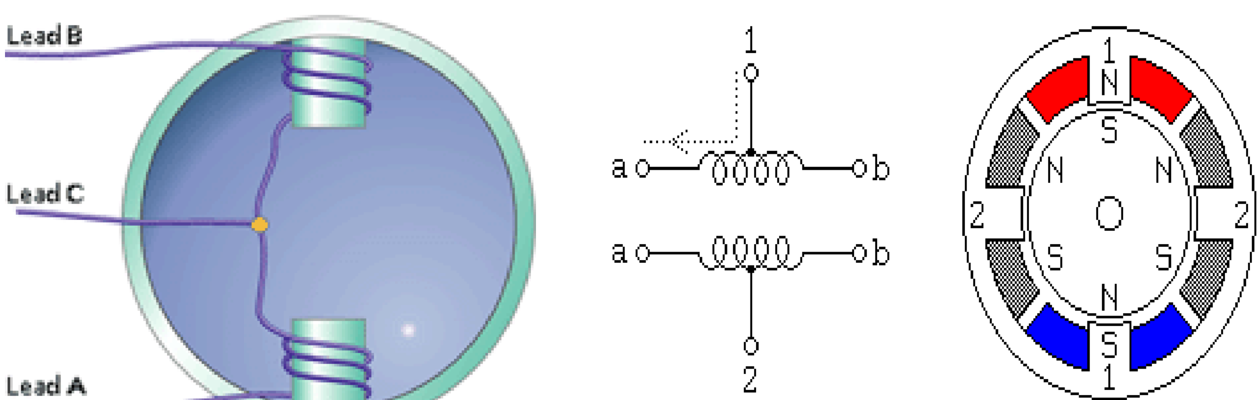


Figure-5.10 A unipolar motor winding

The motor cross section shown in Figure 5.10 is of a 30 degree per step permanent magnet or hybrid motor -- the difference between these two motor types is not relevant at this level of abstraction. Motor winding number 1 is distributed between the top and bottom stator pole, while motor winding number 2 is distributed between the left and right motor poles. The rotor is a permanent magnet with 6 poles, 3 south and 3 north, arranged around its circumference. For higher angular resolutions, the rotor must have proportionally more poles. The 30 degree per step motor in the figure is one of the most common permanent magnet motor designs, although 15 and 7.5 degree per step motors are widely available. Permanent magnet motors with resolutions as good as 1.8 degrees per step are made, and hybrid motors are routinely built with 3.6 and 1.8 degrees per step, with resolutions as fine as 0.72 degrees per step available.

To rotate the motor continuously, we just apply power to the two windings in sequence. Assuming positive logic, where a 1 means turning on the current through a motor winding, the following two control sequences will spin the motor illustrated in Figure 1.2 clockwise 24 steps or 4 revolutions:

```
Winding 1a 1000100010001000100010001
Winding 1b 0010001000100010001000100
Winding 2a 0100010001000100010001000
Winding 2b 0001000100010001000100010
             time --->
Winding 1a 1100110011001100110011001
Winding 1b 0011001100110011001100110
Winding 2a 0110011001100110011001100
Winding 2b 1001100110011001100110011
             time --->
```

Note that the two halves of each winding are never energized at the same time. Both sequences shown above will rotate a permanent magnet one step at a time. The top sequence only powers one winding at a time, as illustrated in the figure above; thus, it uses less power. The bottom sequence involves powering two windings at a time and generally produces a torque about 1.4 times greater than the top sequence while using twice as much power.

The simple motor shown in Figure 5.11 is called a *two-phase, two-pole motor* because the stator has two phases (windings), and the rotor has two magnetic poles. If we send current through winding 1 in the direction shown in Figure 5.11a, with no current through winding 2, the rotor will naturally align itself in the direction shown in Figure 5.11a, with its south pole pointing in the north direction of the stator's magnetic field.

Now suppose we remove current from winding 1 and instead apply current to winding 2 in the direction shown in Figure 5.11b. The stator's magnetic field will point to the left, and the rotor will rotate such that its south pole is aligned with the stator's magnetic field. Next we remove current from winding 2 and apply current to winding 1 in the direction shown in Figure 5.11c Note that the current in winding 1 is opposite the current shown in Figure 5.11a. This will result in a stator field pointing down, so the rotor will rotate to the position where its south pole is pointing down.

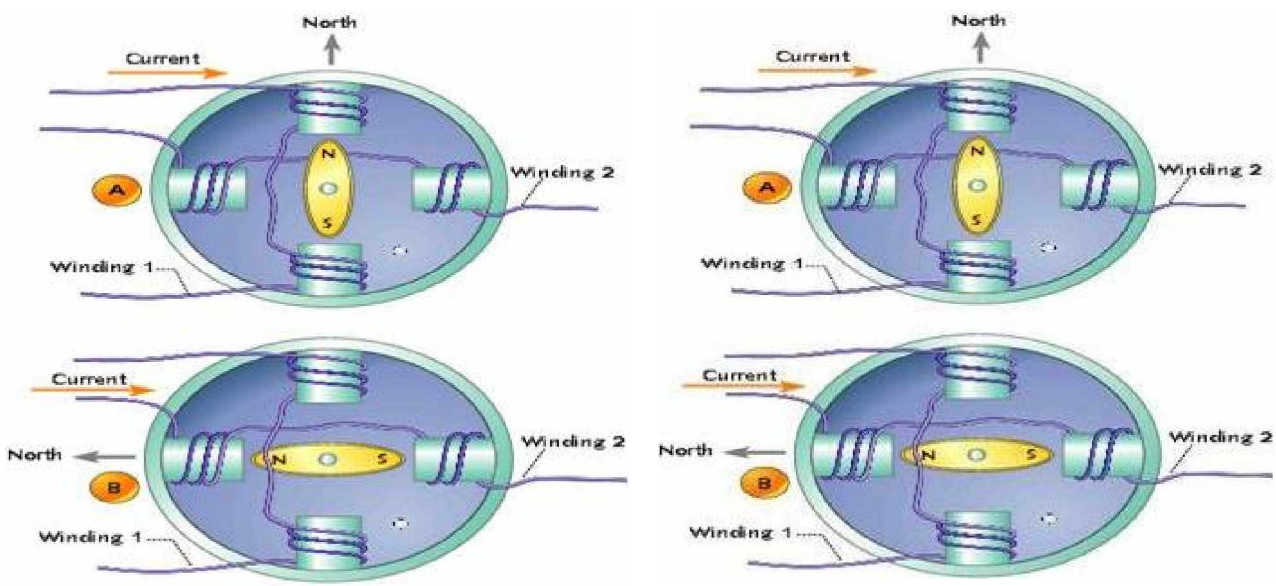


Figure-5.11 A two-phase, two-pole motor

Next we remove current from winding 1 and apply current to winding 2 in the direction shown in Figure 5.11d. This will result in the stator field pointing to the right, so the rotor will rotate to the position where its south pole is pointing to the right. Finally, we remove current from winding 2 and apply current to winding 1 in the direction shown in Figure 5.11a, returning the rotor to the original position. At this point we have completed one cycle of *electrical excitation* of the motor windings, while the rotor has rotated one complete revolution. In other words, the *electrical frequency* of the motor is equal to the *mechanical frequency* of the motor.

If we take one second to sequence through the four steps shown in Figure 5.11, the electrical frequency is 1Hz. The rotor has rotated once, so the mechanical frequency is also 1Hz. In general, for a two-phase stepper, it can be shown that the relationship between electrical and mechanical frequency is given by the equation:

$$f_e = f_m P / 2 \quad (1)$$

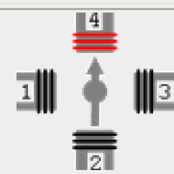
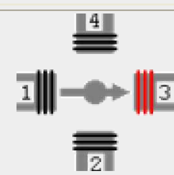
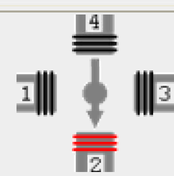
where fe is the electrical frequency, fm is the mechanical frequency, and P is the number of equally-spaced magnetic poles on the rotor. We also can see from Figure 4.11 that one step of the motor results in a rotation of 90°. In general, for a two-phase stepper, it can be shown that one step results in a rotation given by the equation:

$$1 \text{ step} = 180^{\circ} / P \quad (2)$$

This equation says that a two-pole motor will rotate $180^{\circ}/ 2 = 90^{\circ}$ per step, which is consistent with what we observe in Figure 5.11. The equation also shows that a greater number of poles results in better stepping resolution. It is common to find two-phase steppers with anywhere between 12 and 200 poles, which results in a stepping resolution of anywhere between $15^{\circ o}$ and $0.9^{o\circ}$.

Single-Coil Excitation

Each successive coil is energized in turn. [28]

Step	Coil 4	Coil 3	Coil 2	Coil 1	
a.1	**on**	off	off	off	
a.2	off	**on**	off	off	
a.3	off	off	**on**	off	

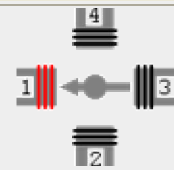
a.4	off	off	off	**on**	

Figure-5.12 Single-Coil Excitation

5.5.3 Motor Controlling

The motor control theory discussed earlier in this article can be implemented with a hardware-only solution, a microcontroller, or a DSP.A two-phase unipolar motor can be controlled by using transistors as switches. Each transistor needs to have its base connected to one of the microcontroller's digital outputs. These four connections are made through resistors (in the 1 to 10 MW range) to limit the current to the bases of the transistors. The emitter of each transistor is connected to ground, and the four collectors are connected to the four end leads of the motor windings. The center-tapped motor leads are connected to the positive terminal of the voltage supply.

Each collector is also connected to the voltage supply through a diode, to protect the transistor from the voltage induced in the motor windings during rotation. (Suffice it to say that as the rotor rotates, a voltage is induced in the motor windings. This voltage will pump current into the collectors of the transistors unless we connect the collectors through a diode to the voltage supply.)

5.6 ULN 2003A

Ideally suited for interfacing between low-level logic circuitry and multiple peripheral power loads, the Series ULN2003A high-voltage, high-current Darlington arrays feature continuous load current ratings to 500 mA for each of the seven drivers. At an appropriate duty cycle depending on ambient temperature and number of drivers turned ON simultaneously, typical power loads totaling over 230 W (350 mA, 95 V) can be controlled. Typical loads include relays, solenoids, stepping motors, magnetic print hammers, multiplexed LED and incandescent displays, and heaters. All devices feature open-collector outputs with integral clamp diodes.

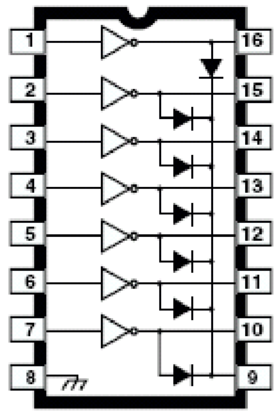


Figure-5.13 ULN 2003A

The ULN2003A have series input resistors selected for operation directly with 5 V TTL or CMOS. These devices will handle numerous interface needs particularly those beyond the capabilities of standard logic buffers. It has standard Darlington arrays. The outputs are capable of sinking 500 mA and will withstand at least 50 V in the OFF state. Outputs may be paralleled for higher load current capability. These Darlington arrays are furnished in 16-pin dual in-line plastic packages (suffix "A"). All devices are pinned with outputs opposite inputs to facilitate ease of circuit board layout. All devices are rated for operation over the temperature range of -20^{o}C to +85^{o}C. Most are also available for operation to -40^{o}C; to order, change the prefix from "ULN" to "ULQ". [29]

Features

- TTL, DTL, PMOS, or CMOS-Compatible Inputs
- Output Current to 500 mA
- Output Voltage to 95 V
- Transient-Protected Outputs
- Dual In-Line Plastic Package or Small-Outline IC Package

5.7 Position Sensors or Linear Position Sensors

Capacitance sensors are used with both conductive and nonconductive materials, but are very sensitive to environmental variables. Eddy current sensors contain two coils: an active coil that indicates the presence of a conducting target, and a secondary coil that completes a bridge circuit.

Fiber optic sensors use a pair of adjacent fibers to carry light to a target and receive reflected light from the object.

Inductive sensors are non-contact devices that determine an object's coordinates with respect to a reference point. Linear encoders sense and digitize position changes for control systems.

Linear potentiometers produce a resistance output proportional to an object's displacement or position. Linear variable differential transformers (LVDT) produce electrical outputs proportional to the position of a solid, cylindrical core. With magnetoresistive sensors, the resistance of a conducting strip is a function of the direction and magnitude of an applied magnetic field.

Proximity sensors detect the presence of an object without physical contact. These sensors transmit and receive the high frequency oscillations or any other type of waves. The span time is related with the distance or the position.

Photoelectric sensors use reflected beams of light to measure distance or displacement.

Ultrasonic sensors reflect acoustical signals and calculate distance based on the signal's return time and the measurement medium's propagation velocity.

In the above mentioned position sensors the Proximity sensors are most convenient for the LINAC machine. The explanation is given below.

5.7.1 Proximity sensors

Offered in both plastic and metal housings, these proximity sensors are interchangeable with existing sensors of similar characteristics or can be designed specifically for individual application needs. The standard operating temperature range is from -40°C to 125°C (-40°F to 257°F).

Features

- Fully potted switch and leads
- High cycle rate capabilities
- High-speed operation
- Compact for limited-space applications
- No moving parts, for longer life
- Corrosion-resistant

- Wide selection of materials
- Engineered designs available
- Can sense 1 mm thick square target
- Provided with LED indicators

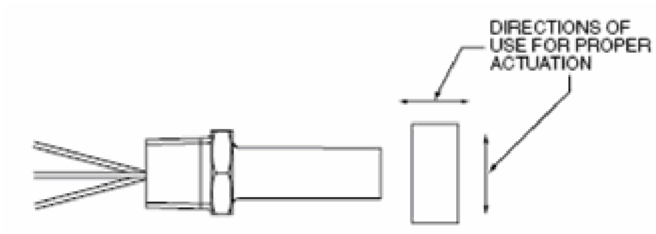


Figure – 5.14 proximity sensor

Inductive & Capacitive

Their operating principle is based on a high frequency oscillator that creates a field in the close surroundings of the sensing surface. The presence of a metallic object (inductive) or any material (capacitive) in the operating area causes a change of the oscillation amplitude. The rise or fall of such oscillation is identified by a threshold circuit that changes the output state of the sensor. The operating distance of the sensor depends on the actuator's shape and size and is strictly linked to the nature of the material. A screw placed on the back of the capacitive sensor allows regulation of the operating distance.

Photoelectric

These sensors use light sensitive elements to detect objects and are made up of an emitter (light source) and a receiver. Three types of photoelectric sensors are available. Direct Reflection - emitter and receiver are housed together and uses the light reflected directly off the object for detection. Reflection with Reflector - emitter and receiver are housed together and requires a reflector. An object is detected when it interrupts the light beam between the sensor and reflector. Thru Beam - emitter and receiver are housed separately and detect an object when it interrupts the light beam between the emitter and receiver.

Magnetic

Magnetic sensors are actuated by the presence of a permanent magnet. Their operating principle is based on the use of reed contacts, which consist of two low reluctance ferro-magnetic reeds enclosed in glass bulbs containing inert gas. The reciprocal attraction of both reeds in the presence of a magnetic field, due to magnetic induction, establishes an electrical contact.

Ultrasonic proximity sensors

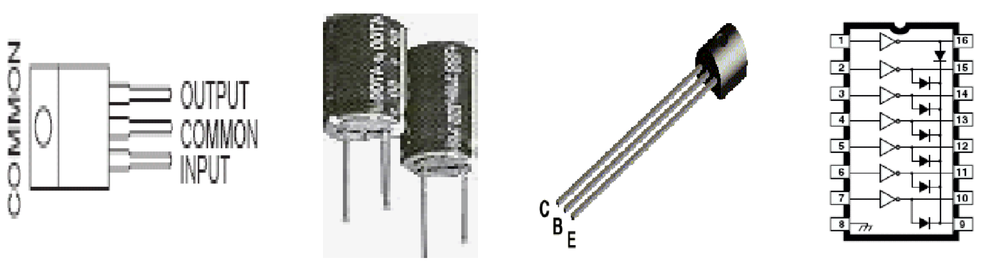
Ultrasonic proximity sensors use reflected or transmitted ultrasonic waves to detect the presence or absence of a target component. The output is Boolean, that is, the sensor merely detects whether the target is or is not within the design detection range. The measurement of proximity, position and displacement of objects is essential in many different applications: valve position, level detection, process control, machine control, security etc. Proximity sensing is the technique of detecting the presence or absence of an object using a critical distance. A position sensor determines an object's coordinates (linear or angular) with respect to a reference, displacement means moving from one position to another for a specified distance (or angle). In effect, a proximity sensor is a threshold version of a position sensor.

Specifications

Maximum Voltage	120 VDC; 120 VAC
Maximum Switching Amps	3 A
Watts (max.)	100 W
Breakdown Voltage	250 VDC
Operating Temperature	-40°C to 125°C
Standard Actuator Size	1.125” x .470”
Operating Time	3 msec
Release Time	3 msec

Component	Qty
AT89C51 Microcontroller (IC2)	1
12 MHz Crystal -1	1
Capacitors 33pF (for crystal cktry)	2
Capacitor(power cktry)1000μF	1
Capacitor (power on reset ckt) 2.2μF	1
Resistor 8.2k	1
Regulator IC7805 (IC1)	1
LCD 5×7 matrix, 16×2	1
Push Switches	3
ULN2003A IC (IC3)	2
Stepper motor	2
Transformer (909)	2

Table-5.4



Regulator 7805 Capacitor transistor 369 ULN2003A

Figure - 5.15 Components

Chapter-6

Software Implementation

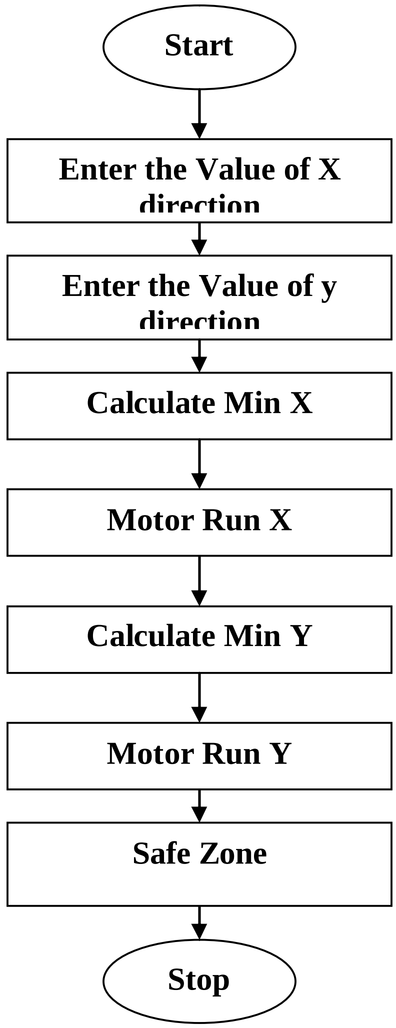
The programming of the 8051 is done in embedded -C language. It is used because of the following advantages:

- To speed up computer operation.
- To reduce the size of the program.
- To write programs for special situations.
- To have better understanding of the computer operation.

6.1 Keil Software

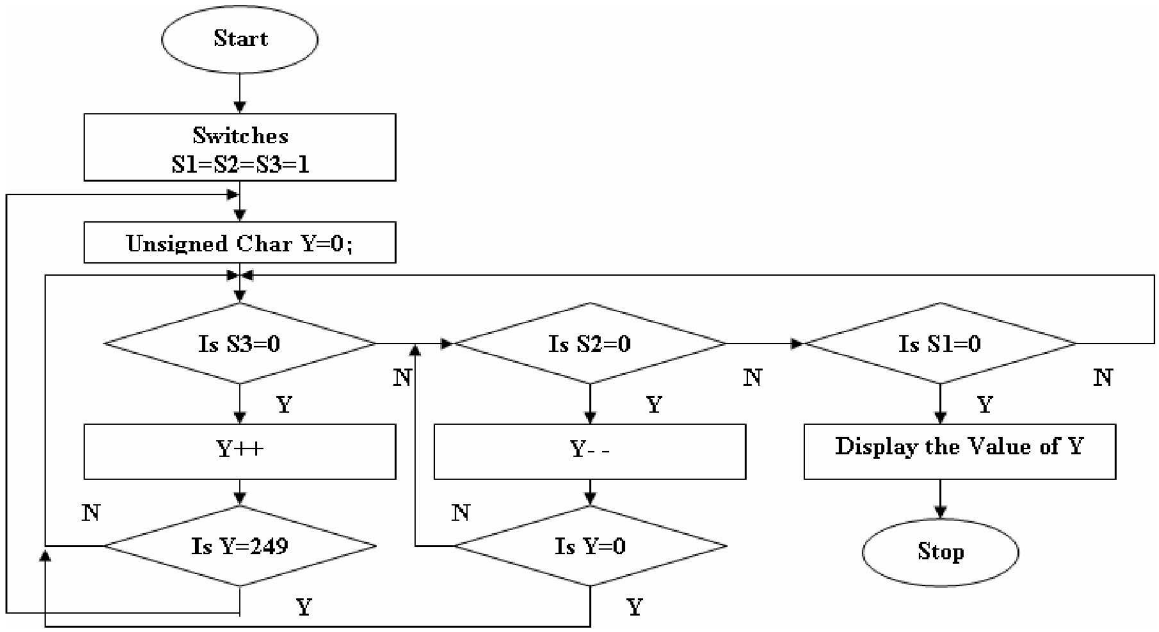
Keil software is used for the software implementation of the developed system. µVision2 Integrated Development Environment is an IDE that encapsulates a project manager, make facility, tool configuration, editor and a powerful debugger. µVision2 is used to write and compile the programs using the tools. It can transfer the assembly language as well as C code into the HEX file. [30]

6.2 Flowcharts of program



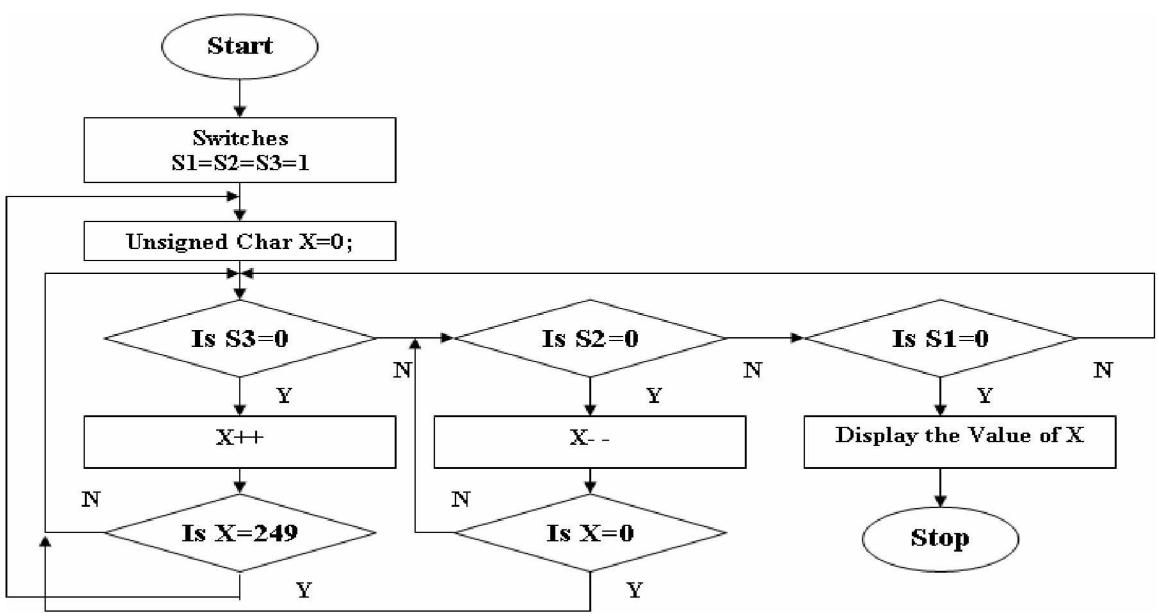
Flowchart 1 Main Program

In this program we are entering manually the distance values of the patient couch from the isocenter, we call it the present value. The values represent the two co-ordinates values x and y. In actual and complete anti-collision device these x and y will Now the difference arrays are calculated which are the difference of the values of safe zone to the present value of the patient couch. Now minimum value from each difference array is calculated and motor is rotated accordingly to take patient couch in safe zone. The blocks Motor run X and Motor run Y signifies the motor movement for x and y direction correspondingly.

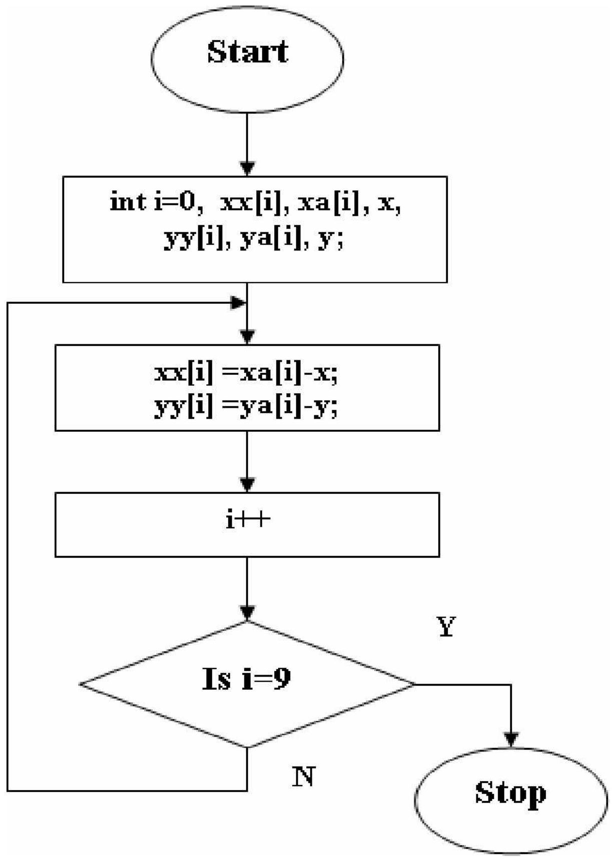


Flowchart 2 Enter the Value of Y direction

The working of above and below flow chart is almost same. These flow charts involve the steps to show how we can increment and decrement any value using switches and simultaneously displaying the value on LCD module and selecting any value in the range defined in the program.

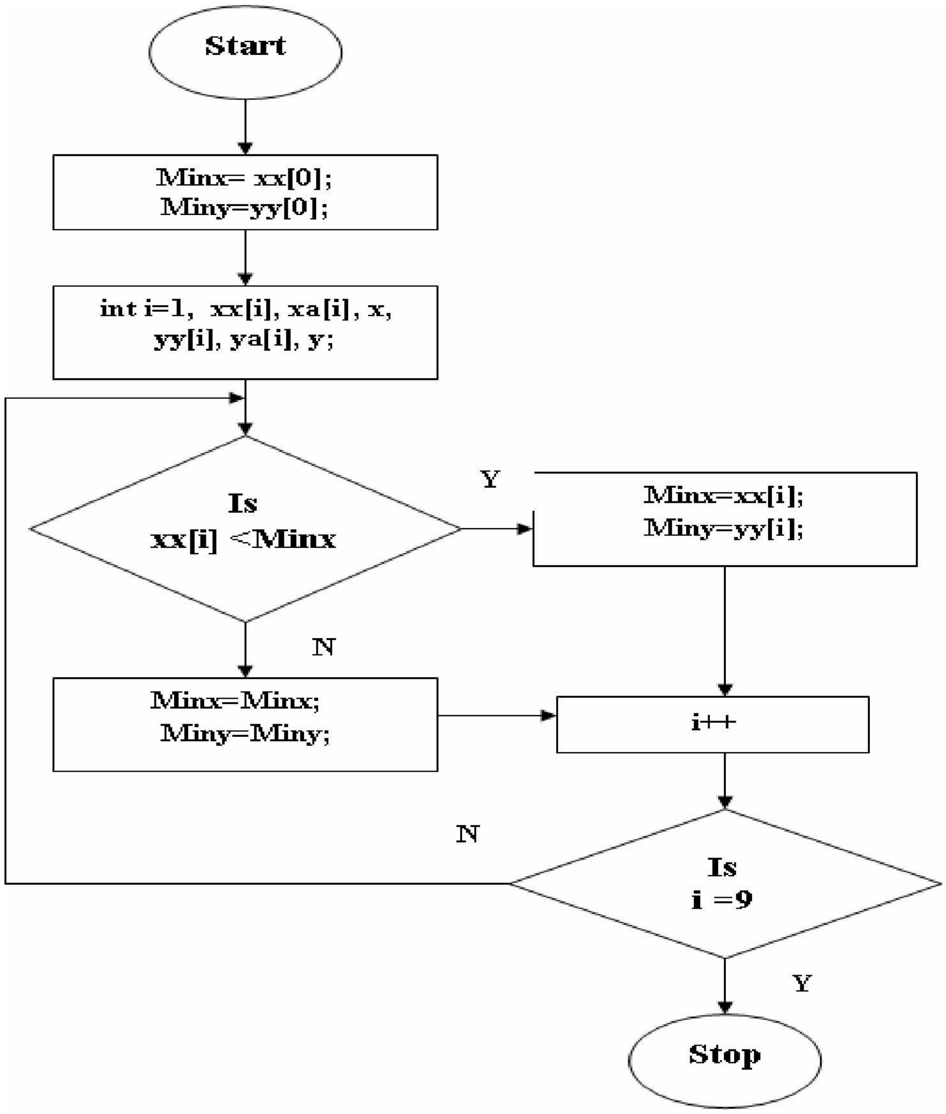


Flowchart 3 Enter the Value of X direction



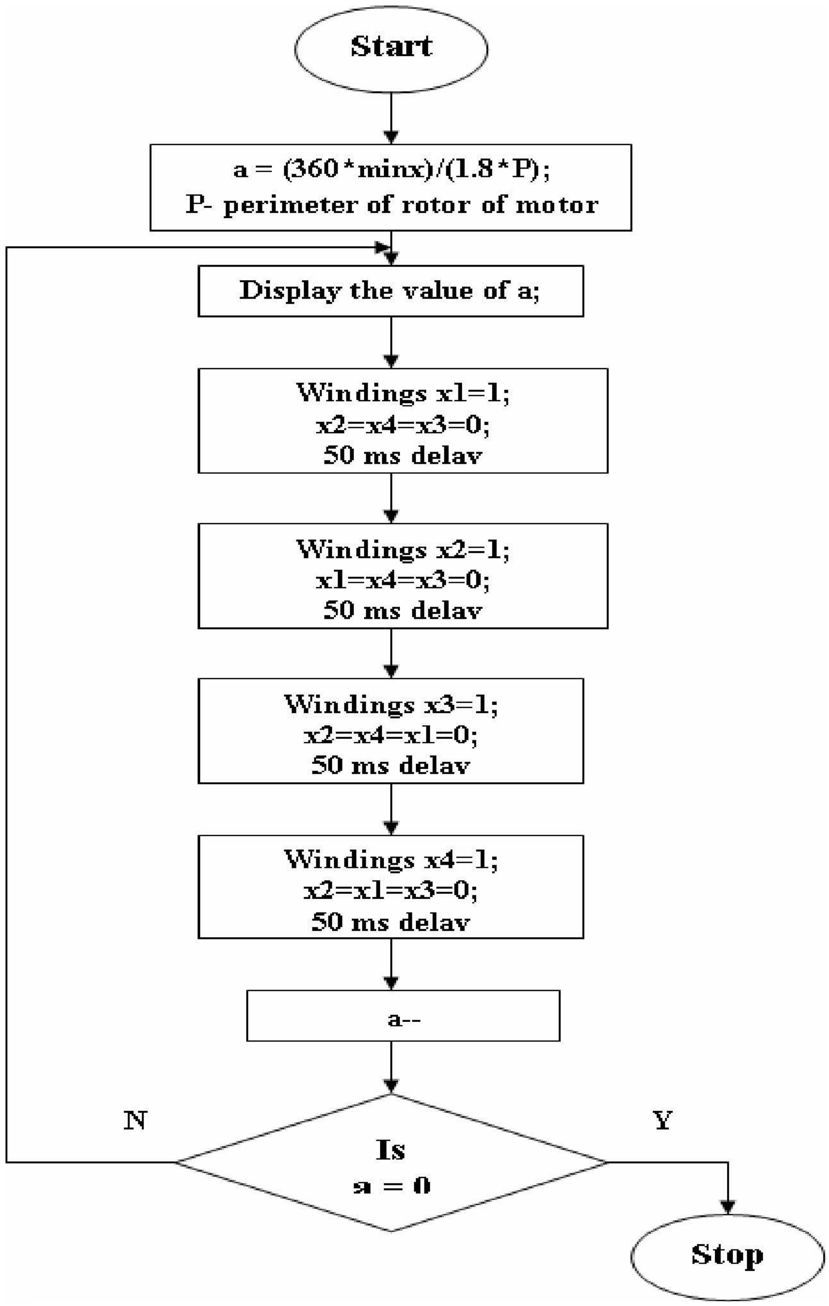
Flowchart 4 Calculate Difference Array

In the above the steps to calculate difference array are shown. Here xa[i] and ya[i] are the arrays, which contains the no collision zone measurements, x and y are the outputs of sensors to specify the present position of patient couch. xx[i] and yy[i] are the difference array.since we have demo version of keil compiler software so it takes 10 values maximum that's why i=9.



Flowchart 5 Calculate minimum value from Difference Array

In the above shown flow chart the steps involved in getting the minimum distance of patient couch from the isocenter are explained. The first element of the difference array is supposed to be minimum and now it is compared with the other element of the array. Now if the second element is minimum then the previous minimum value is replaced with it otherwise the minimum value remains the same. Now this loop is executed till the last element. And at last the minimum value is displayed.

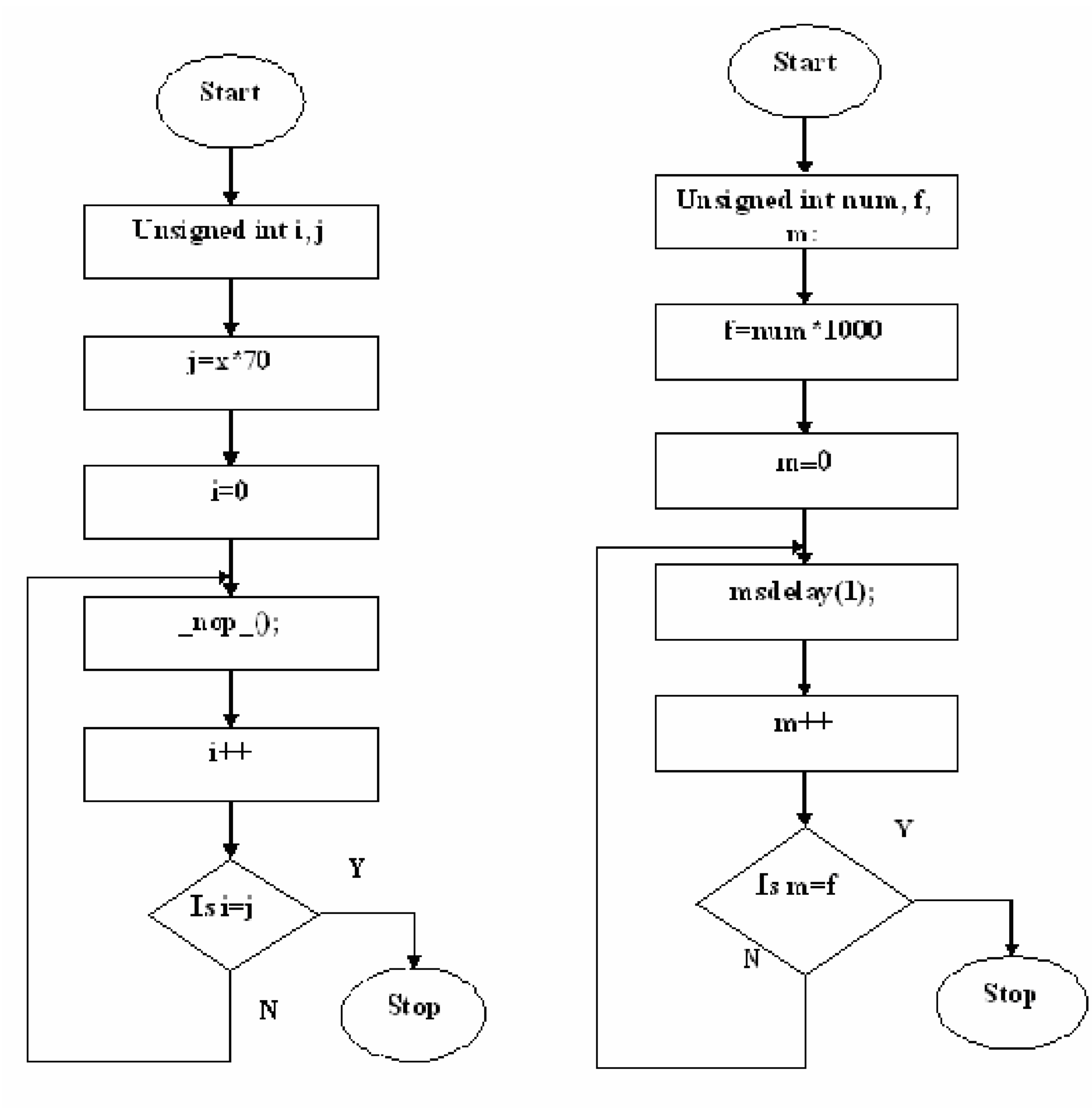


Flowchart 6 Running four winding stepper motor in one coil excitation

In this flow chart the calculations involved in deciding the rotations of the motor and the sequence of one coil excitation are shown. Any variable a is taken where

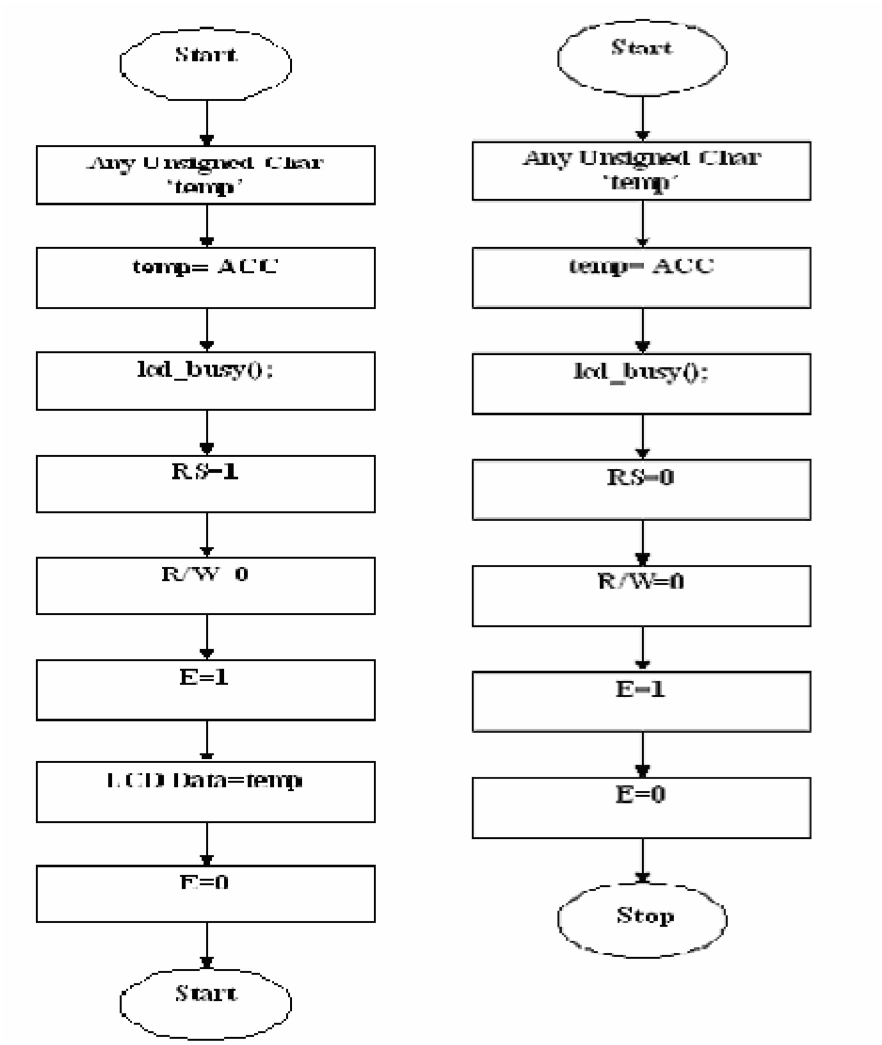
$$a = \frac{360 * \text{minimum difference value}}{\text{Step angle of motor} * \text{Perimeter of rotor of motor}}$$

Now the step sequence shown above is given at the windings of the stepper motor. And 'a' is decremented after applying one full step sequence. And the coils are excited until the 'a' is reduced to zero.



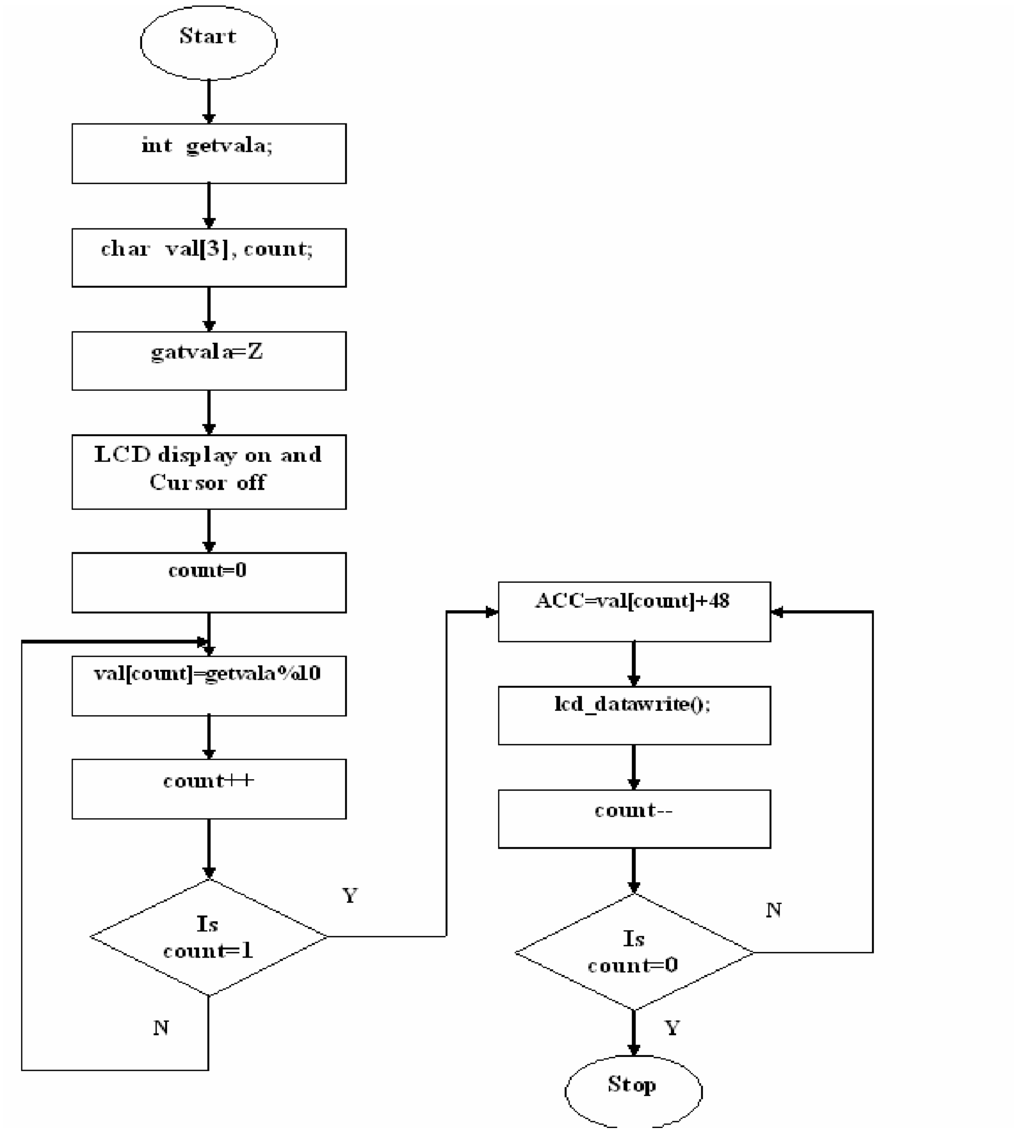
Flowchart 7 Milli-Second Delay and Second Delay

In the flow charts shown above the delay functions are made for making a milli-second delay an instruction _nop_(); is executed number if times, we require that delay. And for making second delay the milli-second delay subroutine is executed 1000 times.



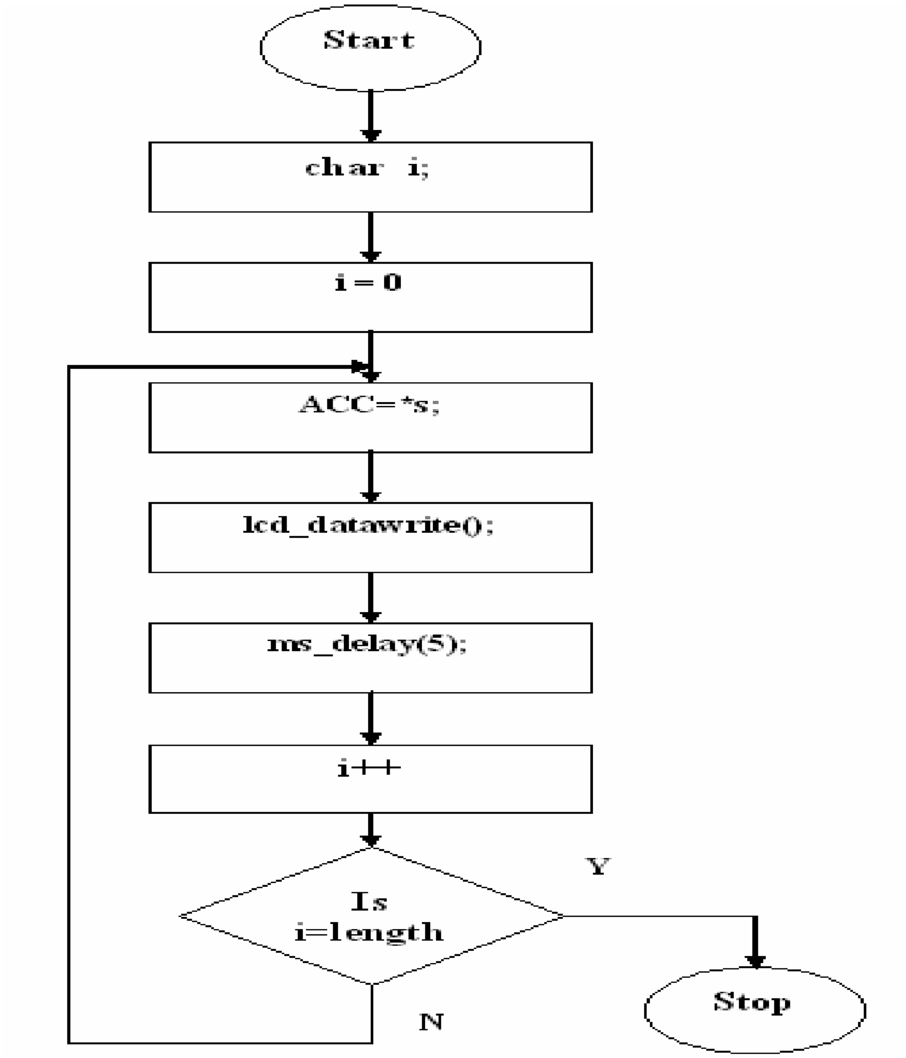
Flowchart 8 LCD Command and LCD Data Modes

LCD work in two modes one is command mode and the other is data mode In the flowcharts of the third figure the LCD's two modes are shown. There are three control pins of LCD module register select (RS), read/write (R/W), Enable (E). To get LCD in command mode the RS and E are made high and R/W is made low. To get LCD in data mode RS is made low, E is made high and R/W is again made low.



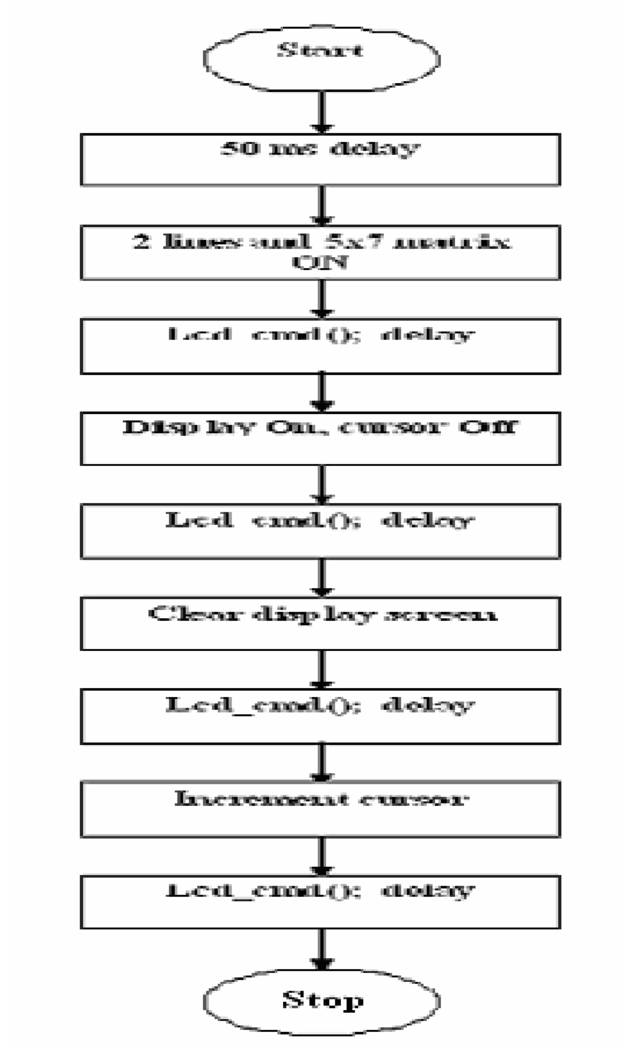
Flowchart 9 Display value of any unsigned character Z

In the above flow chart, the steps involved, in displaying any unsigned integer value, are shown. The integer is taken as getvala and here the integer taken is placed in the form of array of 3 elements on the LCD module. A character count is taken to place the integer at that particular array index on LCD module and we reach at the next array index by incrementing the count. LCD display is made on and Cursor is made off. The count begins from zero and the number is divided by 10. We add 48 to the remainder to make it ASCII code. The LCD understands the ASCII code and the code is given to LCD and the number is displayed on the LCD at that particular location. The whole procedure is repeated for the quotient until all the numbers are displayed.



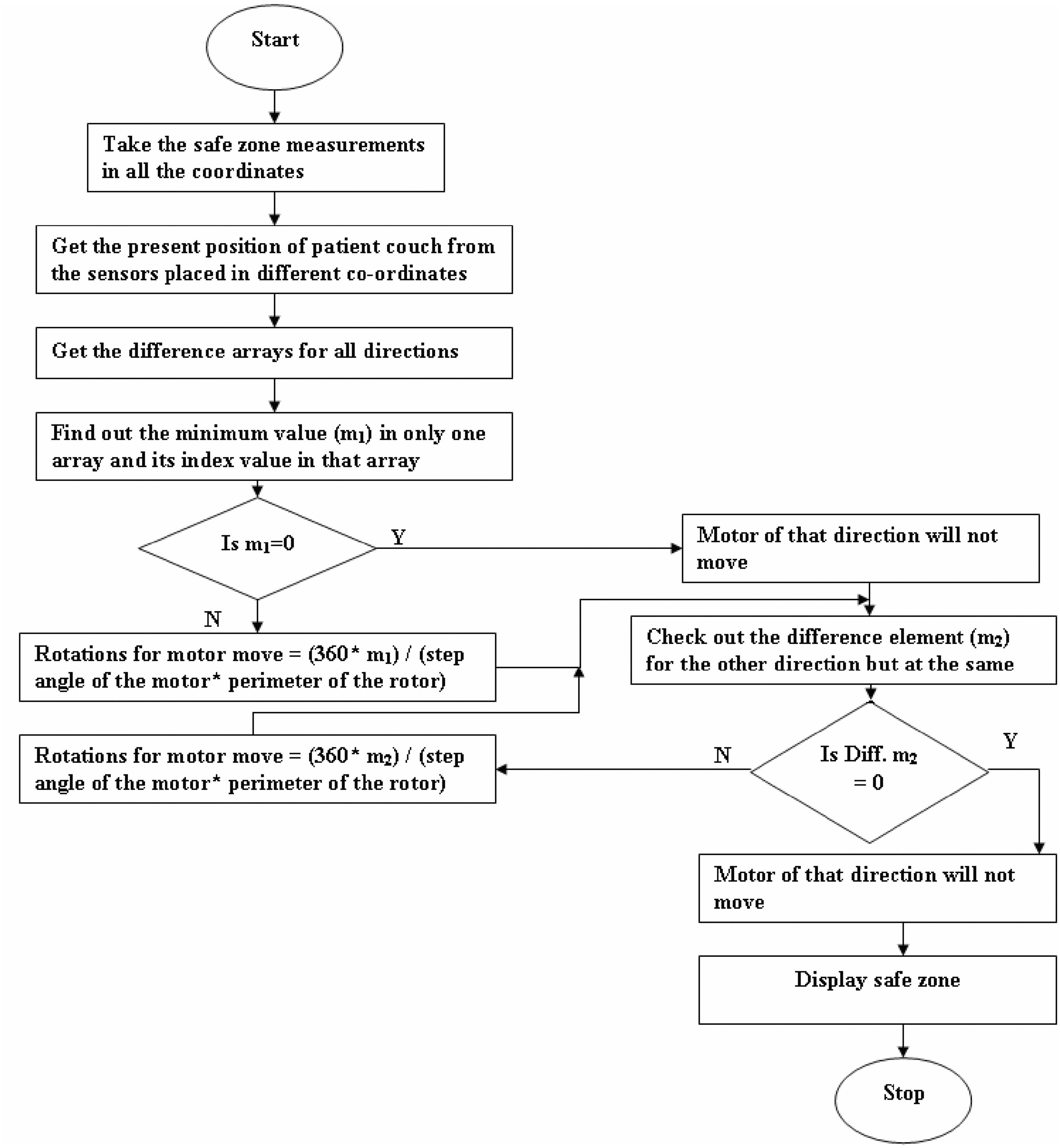
Flowchart 10 lcd_display (char *s, char length)

The above shown flow chart tells the steps involved in writing comments or we can say the characters on the LCD module. The character to be displayed on the LCD is taken in the string data type it is placed in inverted commas and the length of the string is defined. After that the function for writing the data is called. And that string is displayed on LCD module.



Flowchart 11 LCD Initialize

In these flow charts the LCD initialization steps are shown. The steps can vary according to programming needs. Here 2 lines, 5x7 matrix is initialized and the screen is cleared and cursor is off when display is on. All the time the display is on in system therefore the cursor is done off in this function and it is called in the program when required.



Flowchart 12 System working

The above flow chart includes the steps for the whole system working. The sensors for measuring the distance of the patient couch from the isocenter are placed on the LINAC machine. The readings for which the patient couch is in safe zone i.e. in anti- collision zone are taken in all the coordinates using sensors. Now a table is made from the readings and these readings are placed in the form of arrays for different directions. The array is formed to make programming more efficient. Now if we want to check that weather the patient couch is in anti collision zone or not, we measure the present position of the couch using the sensors attached to it. Now the difference array is calculated, which is the difference of the elements of safe zone array and the present position of the couch. By this we get arrays for all the directions separately. Now the minimum value among all the difference arrays is calculated by doing programming. Then the motors run according to these minimum values and the couch in safe zone is achieved. Figure 6.1 shows concluded system diagram.

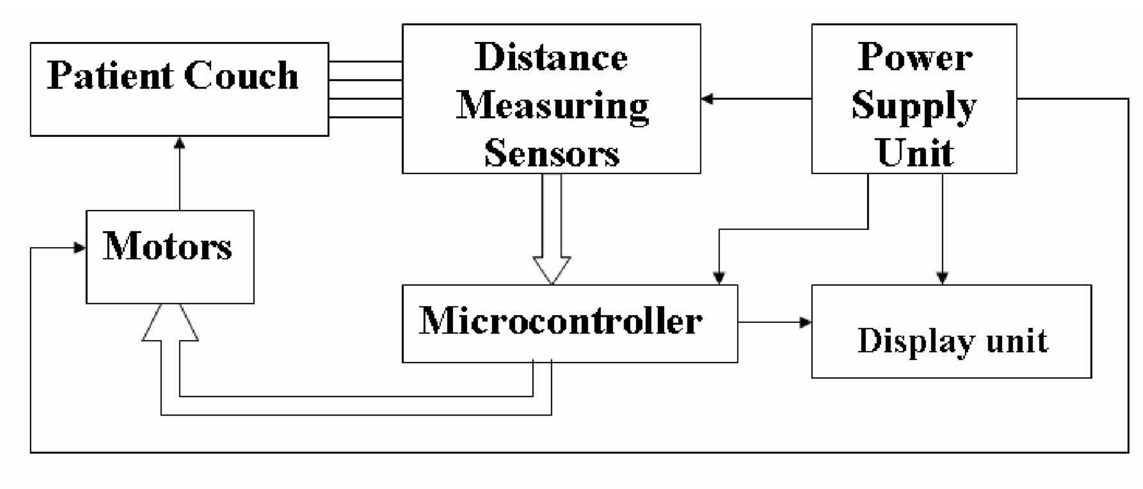
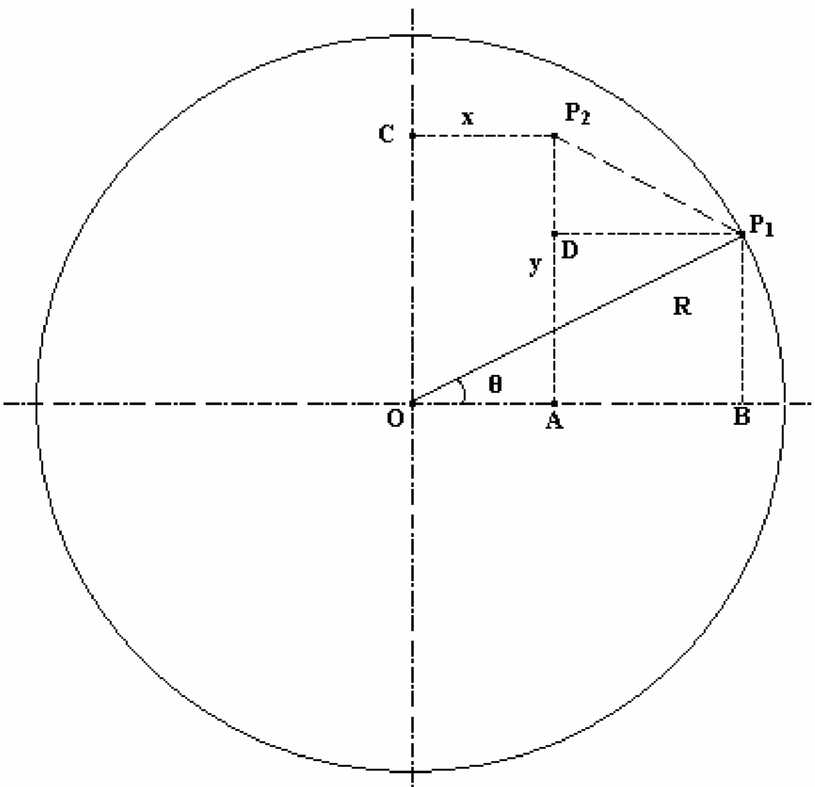


Figure-6.1 Concluded system diagram

Chapter-7
Result and Discussion

7.1 Mathematical Formulation

In order to devise an automatic anti-collision system, a mathematical understanding of the problem is very essential. Figure 7.1 depicts the gantry and patient couch motions in proper relation. The gantry rotates on a fixed circle with the isocentre as its centre. The patient couch, on the other hand, moves in a rectangular zone, as shown in the figure. So that, the collision does not take place between these two moving units, one has to fix safe-gap between them in all possible positions, which they may take in their operation.



P_1 –Pt. on gantry rotation

P_2 –Far most edge of couch

O -Isocentre

R –Gantry rotation radius

Figure-7.1 Geometrical representation of moving points P_1 and P_2

As illustrated in figure 7.1, let us consider a point P_1 which lies on the gantry rotation circle of radius R. The path of this point is fixed and its position on this circle is given by the gantry rotation angle 'θ'. Further, consider a point P_2 which denotes the far most edge of the patient couch top .Point P_2 can be anywhere in the circle of revolution of point P_1. Point P_2 can be defined by the co-ordinates x and y with reference to the centre O. It is required to find straight gap between these two points depending upon their location. From the figure 7.1, it follows that:

$OB = R\ Cos\theta$ and $OA = x$

Distance $P_1D = AB = (OB-OA) = (\ RCos\theta - x\ )$ …………………………. .(1)

Also, $AP_2 = y$ and $AD = BP_1 = R\ Sin\theta$

Distance $P_2D = AP_2 - AD = (\ y - RSin\theta\ )$…………………………………..(2)

Hence, $P_1P_2 = \{ (\ dP_1)^2 + (dP_2)^2 \}^{1/2}$

$= \{ (\ RCos\theta - x\ )^2 + (\ y - Rsin\theta\ )^2 \}$

$= \{ (\ R^2Cos^2\theta - 2RCos\theta + x^2\ ) + (\ y^2 - 2RySin\theta + Sin^2\theta\ ) \}^{1/2}$

$=\{ R^2 (\ Cos^2\theta + Sin^2\theta\ ) - 2RxCos\theta + x^2 + y^2 - 2RySin\theta \}^{1/2}$

$=\{ R^2 + x^2 + y^2 - 2R\ (Cos\theta + ySin\theta\ ) \}^{1/2}$…………………….............(3)

This equation gives an expression for distance between these two moving points P_1 and P_2 .In order that the collision does not take place; there should always be minimum “safe distance”. The moment this distance is reached, the system movements should be stopped.

It is possible to evolve a computerized system based on this equation. The parameters, such as x, y, and θ etc. can be generated as electrical signals by potentiometers or other sensors coupled to the moving units. These, then, can be fed to the controller for further processing.

7.2 Data entries calculated at different safe angles

θ(in degree)	X(in mm)	Y(in mm)
0	205	0
5	203	42
10	197	83
15	188	124
20	176	164
25	160	203
30	140	240
35	118	275
37	108	288
38-142	No collision	zone
143	-108	288
145	-118	275
150	-140	240
155	-160	203
160	-176	164
165	-188	124
170	-197	83
175	-203	42
180	-205	0
185	-203	-42
190	-197	-83
195	-188	-124
200	-176	-164
205	-160	-203
210	-140	-240
215	-118	-275
220	-93	-308
225	-64	-339
230	-33	-367
235	0	-393
236-305	0	-393
310	33	-367
315	64	-339
320	93	-308
325	118	-275
330	140	-240
335	160	-203
340	176	-164
345	188	-124
350	197	-83
355	203	-42
360	205	0

Table-7.1 Data entries at different safe angle

7.2.1 Graph between X-axis and Y-axis

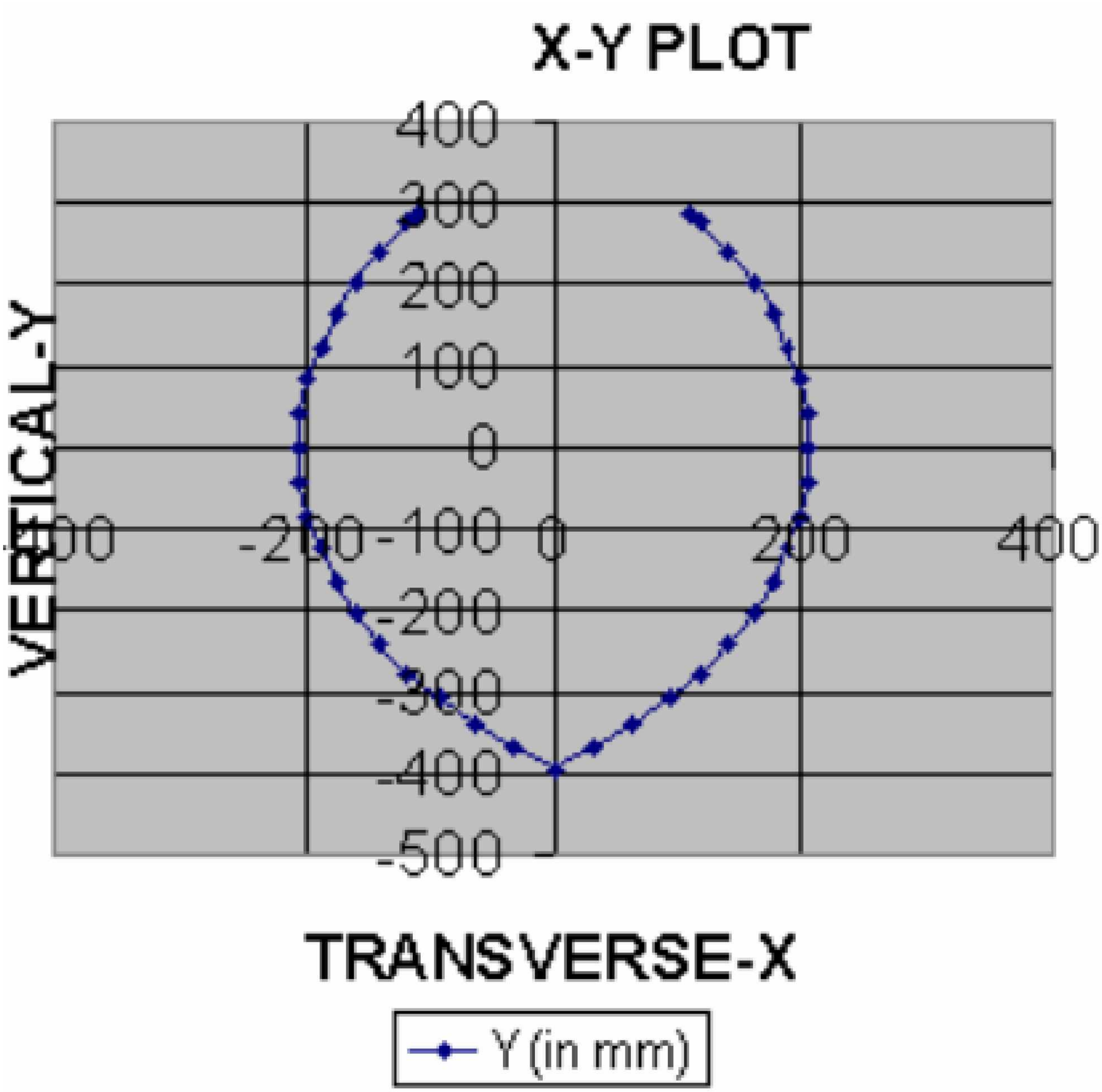


Figure 7.2 X-Y Plot

7.2.2 Set-up time for various position

x(mm)	y{mm)	manual method	with Anti-collision device
		(second)	(second)
215	10	312	55
210	0	316	51
208	25	292	52
205	50	293	58
200	90	310	39
195	93	288	42
190	100	297	65
185	150	302	46
178	170	279	42
170	188	304	43
168	190	301	44
165	210	281	50
162	215	293	55
157	218	308	51
150	220	295	52
148	230	306	58
140	250	306	53
130	255	286	35
120	260	309	37
average time		298	49

Table 6.2 set-up time

7.2.2 Comparison table

	manual method	with Anti-collision device
Set-up time	5 minute	1 minute
Chance of collision	yes	no
Alarm facility	no	yes(audio & visual)
Reliability	no	yes
Patient safety	no	yes
Exposure to radiation for operator	More	Very less

Table 7.3 comparison table

7.3 Verification of the Problem

From the figure 7.1 shown above, the outer circle shows the path of the gantry with OA as gantry radius equal to 495 mm. cc, the width of the table tops i.e. 550 mm. To go safer side of the calculations, let us take the gantry radius as 480 mm instead of 495 mm. Let us discuss the method of calculations, when gantry angles $\theta = 0$ and table is on the iso centre level. Allowable transverse of the tabletop X=480 Cos5-550/2 203 mm and so on.

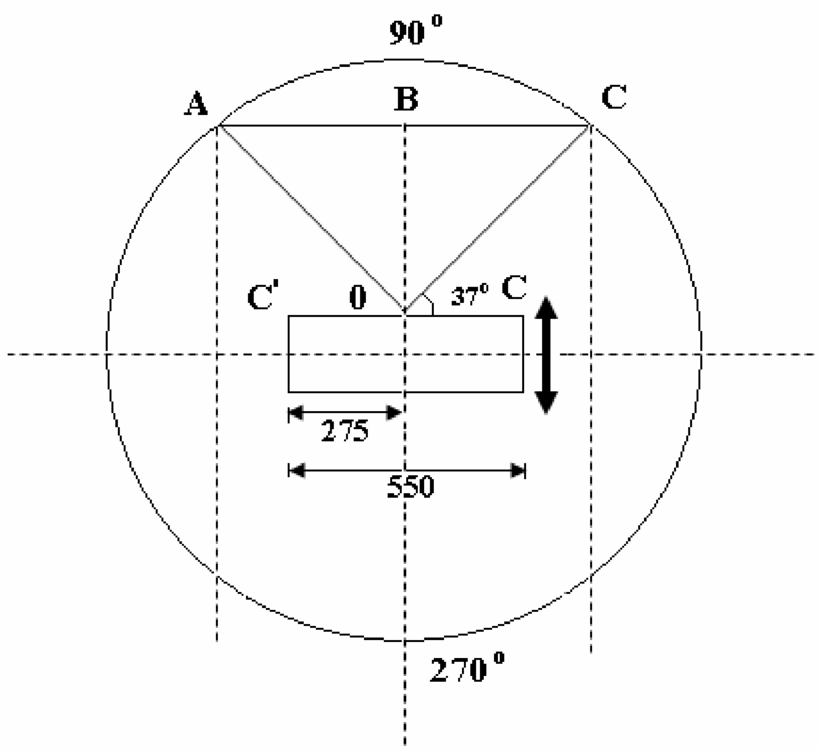


Figure 7.3 verification of problem

The table has been formed with least count of 'θ' as 5°. At the time when cc is rotated (patient couch), it will be required to rotate with 90° and 80°. In that case reading of + z and -z will be same as +x and -x. The corresponding values of y- will remain unchanged. The safe movements of patient couch, tabletop corresponding to angle θ and y position have been tabulated as shown in the table 7.1. All this information is converted from A/D to get the desired results.

θ= can vary from 0-360°

R = constant 480mm

Y=can go upwards to + 290mm.

Can down by -480mm

X=±550mm

OB = 290 (max. y movement of table)

OA = 495 (Gantry radius)

$\theta = \sin^{-1}(290/495) = 35.86°$ say 36°

OC'= 485Cos36°=400

CC'=400-275= 125mm = x

On the point when $y = 290$

above the Iso centre and gantry angle $\theta = 37°$

There are chances of collision

To go to the safer side of calculations, let us take the gantry radius = 495-15 = 480 mm

So further calculations will be done with OA, i.e. Gantry Radius = 480 mm

$\theta = \text{Sin}\,(290/480) = 37°$

$OC' = 480\text{Cos}37° = 386\text{mm}$

CC' = 386-275 = 111 mm (x movement i.e. the cross movement of the table)

7.4 Discussion

The process of optimization of path between gantry and patient couch is carried out using one of several mathematical formalisms and algorithms. With the help of computer predefined calculations are fed to computers, so as to make the process fast and accurate.

Different movement of machine is coupled with potentiometers, which gives D.C. signal. Through precision potentiometer, accurate readings are obtained which are calibrated in terms of voltage readings. Two potentiometers are attached for the control of X-axis and Y-axis and then these signal readings are fed to microcontroller from analog to digital converter, which converts the analog voltage signal to digital signal. From ADC, instant information is given to microcontroller, which compares it with data entries, whether the possibility of collision is there, or not. Unlike the manual placement computer control technology is used which provides much more assurance that the radiation machine will performed within its specifications thereby allowing the optimum pass of Gantry and Patient Couch.

We analyze the data with reference to the gantry position starting from 0° to 360°. It was found that the Y co-ordinate of the Patient Couch is safe. From 0° to 360° of gantry rotation and at various Z-positions of the Patient Couch (from both to top) the +X and - X distances of the Patient Couch have been tabulated. In net shell it can be stated that at a particular gantry angle and at a patient couch height, how much the tabletop could be moved in both X-axis positions. All this data is being planned to put in the memory of the machine so that the machine should work safely.

7.5 Features of the end product

1) Accuracy is ±1%.
2) Fast and accurate.
3) An embedded portable device.
4) Speed of response is 5 milliseconds.
5) Low component cost (approx. Rs. 700/-).
6) Can be battery (by 6V and 9V) operated.

7.6 Conclusion

It is possible to make anti-collision device for medical LINAC machine. This can be done by two methods. One is programming in microcontroller by using mathematical formula and another is by using standard table. The feedback of patient couch location is given by suitable sensor like potentiometers/proximity switches by properly calibration. Anti-collision device improves the performance of machine and most important reduces the chance of collision.

7.7 Future Scope

Thesis "Development of Embedded based Anti-collision Technique for medical LINAC machine" is for developing the formula, safe zone table and software and then comparison to manual method. The future scope of the device is by interfacing with a A/D converter and potentiometer/proximity switches and then mount on actual patient couch. Also this can be done by using modern Artificial intelligence like fuzzy logic.

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