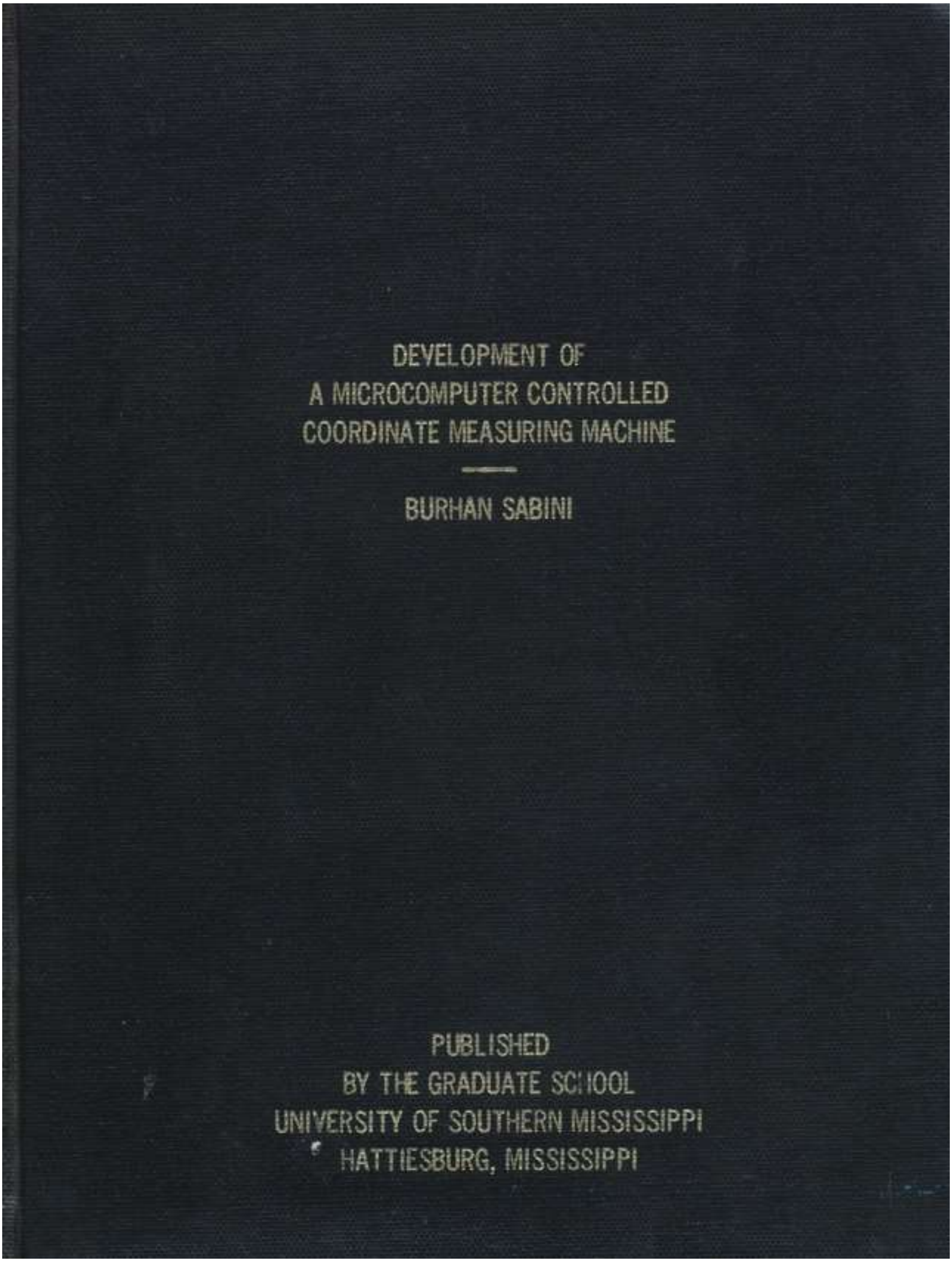


DEVELOPMENT OF A MICROCOMPUTER CONTROLLED COORDINATE MEASURING MACHINE

BURHAN SABINI

PUBLISHED
BY THE GRADUATE SCHOOL
UNIVERSITY OF SOUTHERN MISSISSIPPI
HATTIESBURG, MISSISSIPPI

UNIVERSITY OF SOUTHERN MISSISSIPPI

DEVELOPMENT OF A MICROCOMPUTER CONTROLLED COORDINATE MEASURING MACHINE

By
Burhan Sabini

A Thesis
Submitted to the Graduate School of
the University of Southern Mississippi
in Partial Fulfillment of the Requirements
for the Degree of Master of Science

Approved :

S. Vajpayee
Director

Joe D. Jordan

Dean of the Graduate School

August 1989

ACKNOWLEDGEMENT

I would like to express my gratitude to Professor Gary Johnsey, Professor Kant Vajpayee, Professor Joe Jordan, and Professor Allen Leybourne who served on my committee.

Special thanks to Professor Gary Johnsey for teaching me electronics, giving his support and advice, and donating major components of the CMM : the stepper motors. He gave me many hours of help, starting from the initial design and selection of components to acquisition, assembly, and testing of the hardware and software.

Thanks to Professor Kant Vajpayee for choosing the topic for me, and for helping me with administrative work. Professor Vajpayee provided guidelines and spent many hours correcting the thesis.

Thanks to Professor Joe Jordan for his opinion and suggestions which greatly improved the thesis. Professor Jordan provided important considerations such as comparing the capability of the CMM to those in the industry.

Thanks to Professor Allen Leybourne for encouraging me to get started as soon as possible.

Thanks to Leonard Pilcher of the Industrial Process Center for helping me install the stepper motors and the probe's arm, and for letting me use the machine shop to make modifications.

Thanks to Ira Hajjar for loaning me a Digital Experimenter Board.

Thanks to the School of Engineering and Technology for providing the major funds for this thesis.

Special thanks to my family, Devi Djajaseputra and her parents for their support and encouragement.

Thanks to Mike Seufert for his brief explanation about stepper motors. Moreover, he gave me some tips about using the parallel printer port to communicate with the CMM.

Thanks to Benny Sabini for doing some errands for me.

TABLE OF CONTENTS

CHAPTER

APPENDICES

LIST OF TABLES

LIST OF ILLUSTRATIONS

Figure Page

CHAPTER 1 : INTRODUCTION

In the past, raw materials were abundant and competition was not intense, so most manufacturers did not have to have good control of the quality of their products. Products that did not meet specifications were simply discarded. During that time, the availability of a product was more important than its quality.

Today, the capability to control product quality is important for manufacturers. Most machined or formed parts must be inspected for guaranteeing specified accuracy and quality. The quality control department must take appropriate actions if a part is not within specification limits. Because of recent trends in high production speed, the quality control department must be able to quickly detect any defective parts on-line by comparing the parts with the design data base.

The important characteristics to be inspected in the manufacturing process are quantities, dimensions, tolerance, surface roughness, and defects. Other less important characteristics include color, materials, and weight. This thesis is concerned with one of the main characteristics of parts : dimensions.

Before modern measuring machines were available, people performed the measurement using gages such as indicator or block gages. With the advent of numerically controlled machine tools, especially computer controlled milling and drilling machines, demand grew for a way to do faster inspections. Recently, manufacturers started replacing gages with CMMs (Coordinate Measuring Machine), because CMMs can perform dimensional inspection faster and more reliably. Moreover, CMMs can be automated more easily to keep pace with today's industrial automation. Therefore, having a CMM is essential in today's industrial world.

1.1 OBJECTIVE

The objective of this thesis is to develop a coordinate measuring machine that can be controlled by a microcomputer or a PC. Figure 1.1 shows the basic CMM system to be developed. The components of the system are a CMM, a controller, and a microcomputer. The work involves :

(i) Design and build the controller.
(ii) Modify the existing milling machine in the CIM Lab, if required.
(iii) Write a program to control the CMM.

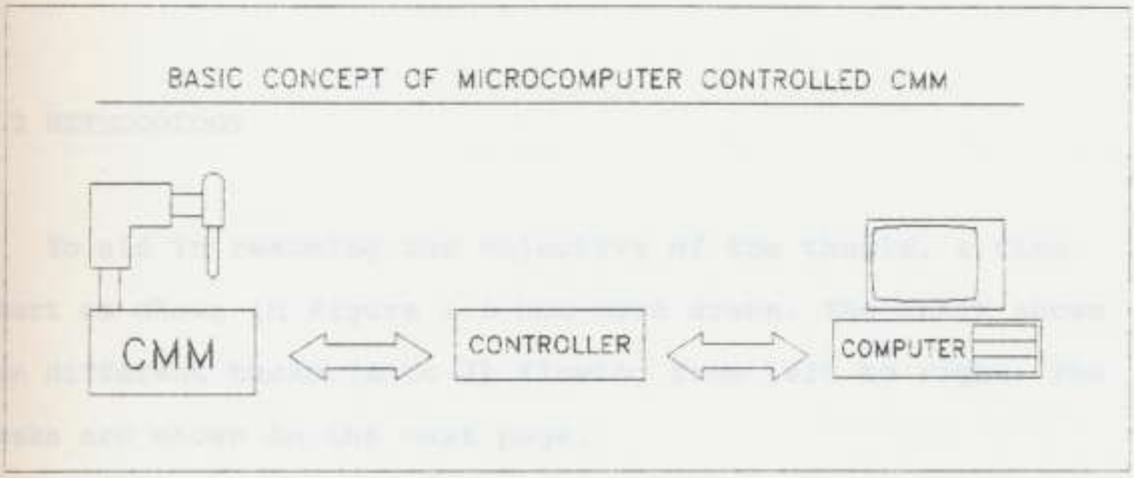


FIGURE 1.1 Basic Concept of Microcomputer Controlled CMM

1.2 METHODOLOGY

To aid in reaching the objective of the thesis, a flow chart as shown in Figure 1.2 has been drawn. The chart shows ten different tasks (A to J) flowing from left to right. The tasks are shown on the next page.

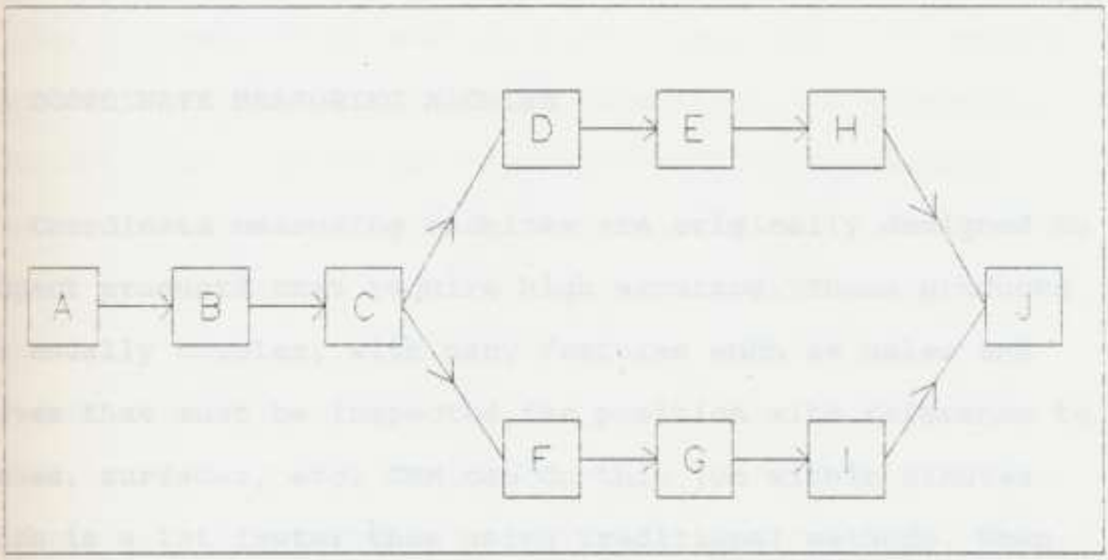


FIGURE 1.2 The Path to reach the objective of the thesis

A	Literature survey on CMM (Starting point).
B	Investigate what is already available.
C	Develop the concept of the CMM system.
D	Determine how to design or modify the CMM's components.
E	Assemble the components.
F	Decide which computer language to use.
G	Write software that can control the probe's path.
H	Test the electronic components.
I	Test the software.
J	Test run the CMM (Stopping point).

CHAPTER 2 : REVIEW OF THE LITERATURE

2.1 COORDINATE MEASURING MACHINE

Coordinate measuring machines are originally designed to inspect products that require high accuracy. These products are usually complex, with many features such as holes and curves that must be inspected for position with reference to planes, surfaces, etc. CMM can do this job within minutes which is a lot faster than using traditional methods. When considering the importance of production time, CMM is clearly an indispensable manufacturing tool for today and the future.

The Basic of CMM

A CMM (Coordinate Measuring Machine) is a tool for taking measurement of the dimension of a manufactured part by tracing and digitizing it. In general, a CMM uses a probe to take measurements in three axes-x,y, and z, permitting dimensional inspection of parts. The part to be measured must be held firmly in place using a workholding device such as a screw clamp, hydraulic clamp or vacuum suction cups.

The most important criteria for a CMM is accuracy. The CMM's accuracy depends on its resolution, which is the machine's finest incremental reading capability, and precision, which is the machine's ability to duplicate identical measurements.

The accuracy of commercially available CMMs are usually stated in terms of linearity, repeatablity, and volumetric accuracy. Linearity is the machine's ability to measure linear surface. Repeatability or precision, as noted above depends on the machine's stiffness. Volumetric accuracy is potentially the best accuracy test of a CMM. The test involves measuring a ball bar, in which the length of a metal rod with precision balls at each end is measured by CMM at various positions within its operating envelope. ANSI Spec B89 for CMM indicates 40 specific positions for the ball bar to determine the CMM's volumetric accuracy [1]. An accurate CMM must perform well in all terms.

Types of Coordinate Measuring Machine

Due to the rapid technology development in today's world, there are many types of coordinate measuring machine now available in the industry. The type of CMM depends on the probe's type. In general, there are two types of probe :

(i) Contact.

(ii) Non-contact.

The star and the electronic are examples of contact probe. Figure 2.1 and 2.2 show these switches and a photograph of a contact-CMM, respectively. Examples of non-contact probe

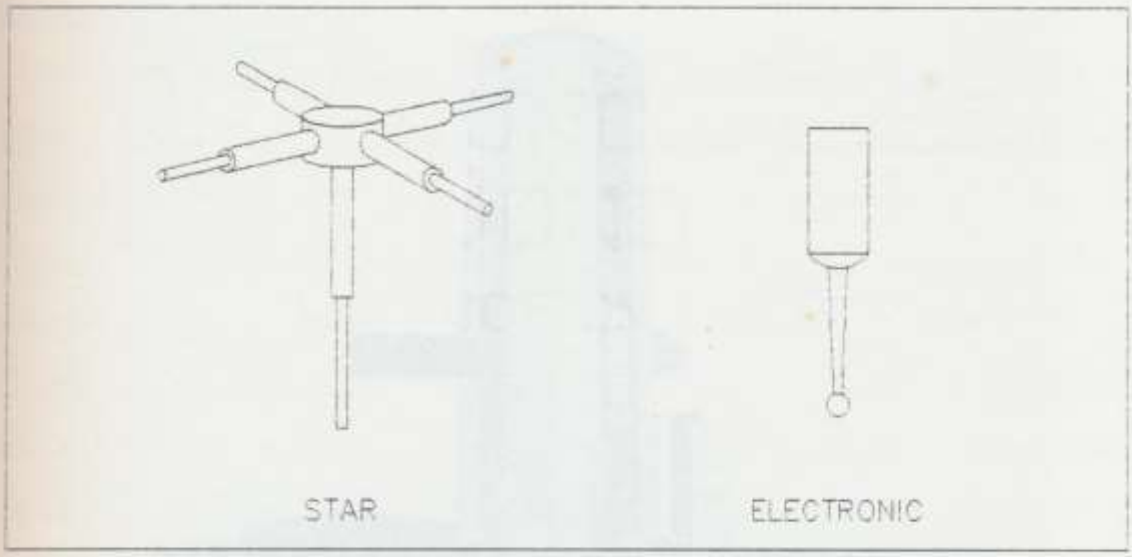


FIGURE 2.1 Examples of Contact probe

FIGURE 2.2 An example of Contact CMM [2]

include laser and camera.

(i) Contact CMM

The Star and Electronic probe differ in their operating methods. The star probe employs three or more legs protruding from the probe's head in different directions. Each leg has a tiny switch which is closed whenever the leg makes contact with the part.

The electronic probe has only one leg with a ball on its end. An example of this system is the Sheffield Measurement's new series of horizontal CMM which is shown in Figure 2.2. The machine has the following specs [2].

- Volumetric accuracy to 17 microns for all four axes combined.
- Repeatability of 0.003mm (0.00012 in.) range.
- Automatic probe offset and temperature compensation.
- Microprocessor enhanced accuracy to prevent 29 different deviations from affecting measurements results.
- Load capacity of 10,000 lb.

Contact CMM is expensive because of the high cost involved in manufacturing the high precision probe. A typical system with 25 micron accuracy and with a working envelope of 18 x 24 inches costs about $20,000 [3].

(ii) Non-Contact CMM

There are three main types of CMM system in this category.

(a) The laser system.

(b) The optical system.

(c) The vision system.

(a) The laser system

This system usually uses carbon dioxide, and is probably the most accurate system. The laser system uses scanning techniques, similar to the raster scan used in most color monitors. The laser, located in front of the object, produces coherent light to scan the object. A light sensor is placed behind the object to detect the interruption of the light beam as it is being blocked by the object. In general, the system's accuracy is limited by the diameter of the laser beam.

(b) The optical system

The optical system uses a video camera to take a magnified picture of the part and display it on a heads-up display so that the operator can measure the part more easily, similar to using a microscope to observe microscopic object. This system is limited by its magnification power. An example of the optical system, shown in Figure 2.3, is the MICRO 5 from Vision Engineering Incorporated [4]. The machine can perform seven to one hundred magnification and has up to

MADE TO MEASURE

Series 5 Multi Axis Measurement

with head up display
- 7-100× magnification
- Up to 8"×6" X-Y capacity with
or 2 micron resolution
- Contact or non contact 'Z' axis measurement
- Adjustable centres with helix angle compensation
- Substage and surface illumination options
- Quick change reticle eyepiece facility
- Standard and customised reticles
- Electronic or manual rotation eyepiece for angle measurement
- Photographic & CCTV interface facility

Micro 5
- Full geometric functions X, Y, Z, angle, radius, circle, skew and polar
- Printer/computer interface via RS232
- Inch/metric conversion
- 100 point memory storage per axis

Circle 50, Reader Service Card

PRECISION WITH Vision

VISION ENGINEERING INC.

570 Danbury Road, New Milford,
Connecticut 06776
Tel: 203-355-3776
Fax: 203-355-0712

765 West Taft, Bata Via Business Center
Orange, California 92668
Tel: 714-974-6966
Fax: 714-

FIGURE 2.3 An example of Non-contact CMM [4]

1 micron resolution.

(c) The Vision System

This system uses one or more video camera and a computer to take pictures of a part from several sides and saves the picture to the computer's main or auxillary memory. Special software separates the image of the part from the background and calculates the part's dimensions. This is the most complex system. It requires vast memory and a high speed microprocessor to manipulate the data. Since memory and high speed microprocessors are expensive, only big companies can afford to buy a high resolution vision system. In the future, when the price of vision systems become affordable, this system will become more popular because it offers benefits that no other systems can offer such as determination of color and temperature.

2.2 ROLE OF CMM IN MODERN MANUFACTURING

Since people judge a product by its quality, manufacturers must maintain the quality of their products. They have to ensure that their products meet specified tolerances and production deadlines while keeping the price down. The introduction of CMM has been an important development in inspection technique. More importantly, by linking CMM to computers, inspection time can be greatly reduced while achieving more accurate measurement as well.

The advantages of CMM over traditional measurement method

Compared to traditional methods such as surface-plate and height gage techniques, CMM offers several advantages. Some of these are :

(i) Lower production cost due to reduction of production time.

(ii) Better accuracy through ease of use.

(iii) Automated inspection.

(i) Lower production cost

In a typical case [5], an operator needed more than two hours, using traditional methods, to inspect a part with 12 holes. By applying CMM, the inspection time could be cut to 15 - 20 minutes. This 85 % reduction in inspection time, shows that CMM is quicker than traditional methods, resulting in lower production cost.

(ii) Better accuracy through ease of use

CMM's volumetric accuracy has been reported to be from 0.001 up to 0.0001 inch [1]. Using traditional methods such as the surface-plate, an accuracy of 0.0001 is possible.

However, the work to achieve such accuracy is difficult and can only be done carefully by experts. CMM can be operated by less skilled operator. Therefore, by minimizing human error, CMM can yield more accuracy than traditional method.

(iii) Automated inspection

Today's CMMs can be controlled by computer while computerized gages, though possible, are not suitable for computer application. With today's trend towards automated manufacturing, CMM should outlast gages in terms of obsolescene. Furthermore, automated inspection has several advantages over manual inspection. As an example, with automated inspection, errors made by doing inspection manually can be reduced to minimal or eliminated altogether. Also, machines can perform inspections for hours, even for days, without losing its accuracy.

These advantages make CMM a better inspection device for many applications requiring high accuracy and automated inspection than traditional methods.

Trends in CMM

In reviewing industrial applications, it becomes apparent that a combination of contact and non-contact probes is needed to complement each other. Several highly accurate CMMs utilizing hybrid probes are becoming available. These CMMs have the capability to take measurement of almost any manufactured part in record time. To extend CMM's flexibility, some companies are trying to develop a probe changers system.

To increase CMM's measurement capability, robots may utilized to move the probe. This technique will enable CMM to take more measurements of complex objects in a single set up.

As computer controlled CMM is becoming more popular, CMM is taken out of the quality control lab and located on the factory as a station in the manufacturing line. On-line CMM provides real time monitoring and feedback for automation process compensation. This way, CMM may operate fully automated with relatively little or no attention at all from even a less skilled operator.

Further enhancement of CMM is possible by linking it to a CAD's data base. Inspection procedure can be created by the designer before a part is ever produced. As a result, parts conformance to specification can be checked, thus saving time and money.

Other applications of CMM

Beside for inspection, CMMs are utilized in manufacturing for many other tasks in production. For example, CMMs are used to monitor a part as it is being cut. If the cut exceeded a certain specified limit, the CMM can send signals to the cutting machine or sound alarms to the operator so that appropriate action can be taken to adjust the cut to within the specified limit.

Other applications of CMM include monitoring tool ware, detemining the correct position of the part, and positioning the machine tools. These applications made CMMs an important machines in flexible manufacturing system which rely heavily on automated machines.

2.3 THE NEEDS OF CIM LAB

The School of Engineering and Technology has a CIM (Computer-Aided Manufacturing) lab in the Chain Technology Building. Future plans for the CIM Lab includes developing FMS (Flexible Manufacturing System). Therefore, CMM which is a component of FMS, is needed. The only way to have a CMM is to either buy it or build one. Since, a commercial CMM is expensive, their cost start from $20,000 [4], a CMM must be built for the lab.

The development of the CMM serves two purposes. First, it will provide a CMM for the lab. Secondly, it is a good topic for education and training.

The cost for developing a CMM will be provided by the

School of Engineering and Technology, because the CMM system will become the school's property.

2.4 THE STEPPING MOTORS

Preliminary investigation suggests that stepper motors are required. Therefore, a literature survey on stepper motors was conducted.

The Principles of Stepping Motors

A stepping motor is a motor possessing the ability to rotate in either direction as well as stop and start at various mechanical rotational positions, and whose shaft (rotor) moves in precise angular increments for each input excitation change or step [6]. The displacement is repeated for each input step command. The result of this type of movement is the motor's ability to accurately position the rotor in a known repeatable direction. Therefore, the stepper motor allows control of position, velocity, distance and direction. Because each step moves the shaft to a known position, the only shaft position error will amount to the single step accuracy. This accuracy is generally five percent of one step [6].

Internal Structure of Stepping Motors

Stepper motor has two rotors and a stator. Figure 2.4 shows the internal configuration of the stepper motor. The rotor consist of an axially-oriented magnet with two gear-like hubs with teeth. The two magnets are 180 degree out of phase from each other and they are not aligned. The stator also has teeth but it is not magnetic. The magnetic poles of the stator's teeth are generated by energizing the windings. The stator teeth are never aligned to the rotor's. The magnetic attraction between the closest stator and rotor tooth, creates predicted movement in the rotor. Even when there is no power on the stator, the magnet will hold its position, although at low torque.

Stepper motors, especially the powerful one, are expensive. A typical stepper motor, 5V at 1 Amp., cost $190 [7]. Also, a stepper motor requires a DC Power supply, motor driver, and logic circuit to operate.

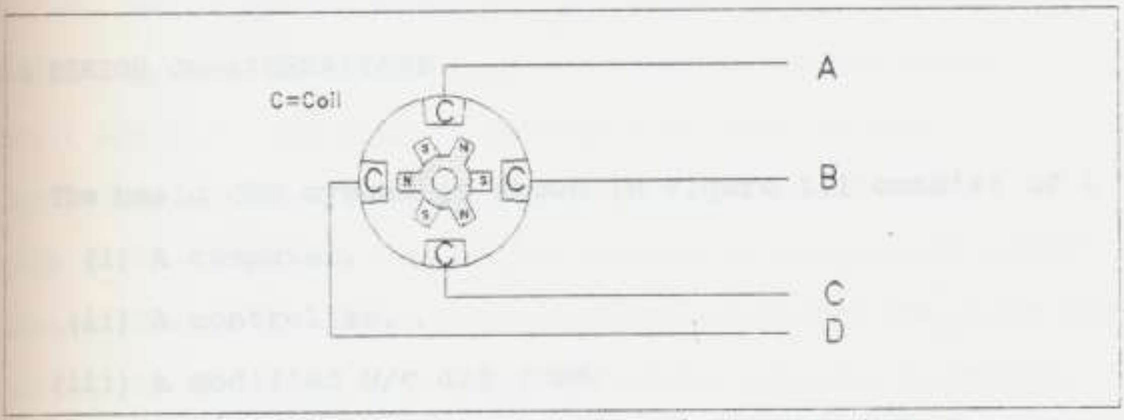


FIGURE 2.4 The internal structure of a stepper motor

A	Phase 1
B	Phase 2
C	Phase 3
D	Pahse 4

CHAPTER 3 : DESIGN AND DEVELOPMENT

3.1 DESIGN CONSIDERATIONS

The basic CMM system as shown in Figure 1.1 consist of :

(i) A computer.

(ii) A controller.

(iii) A Modified N/C 100 (CMM).

Therefore, the first thing to do is check their availability and build or buy the missing components.

(i) Computer

In the CIM Lab there are three computers : two 8088 machines, Tandys and a 80286 machine. The computer chosen for the thesis is the 80286 machine because the other computers are older version of Tandy computers which are known to have compatibility problem with MS-DOS software. Furthermore, the computer's video card is not color and not 100% IBM compatible.

The 80286 machine is IBM PC Compatible and has an Intel 80286 microprocessor, Video Seven's VEGA-VGA board, NEC Multysync II monitor, two serial and two parallel ports. The computer's clock is about 10 MHz (tested using LANDMARK Version 1.02).

(ii) Controller

The computer must have a way to pass its instruction to move the CMM's motor. However, the output signal of the computer is digital and cannot directly drive the motor, thus a motor driver must be provided to amplify the signal. One approach was to buy or build a board that plugs into one of the computer's expansion slots, and motor drivers. The board could include logic circuitry to check the validity of the computer's output before passing it to the motor driver. The board and the motor drivers are commercially available. The cost of such a board and the motor drivers, excluding the DC power supply, are $625 and $345, respectively [7]. Due to their high cost, building the motor driver and the board was a good alternative.

Since, building an internal board is complicated, an external board could be built instead. The board and the motor driver can be placed inside a box external to the computer. In this thesis the controller refers to this external box.

The logic circuit and the motor driver must use separate power supplies so that they will not interfere or harm each other. After checking the power requirement, it was found that the power supply should be five volts for the logic circuit, and twelve and five volts for the stepper motors. Since the logic circuit requires very little current, a 1 amp. power supply should be sufficient. The stepper motors need a larger power supply. Due to budget constrain, a medium size power supply with two voltage outputs - 5V at 5 Amps, 12V at 2 Amps, was purchased.

(iii) Modified N/C 100 (CMM)

The CIM Lab (TEC 122) had a N/C 100 milling machine which was not used anymore and can be modified into a CMM. The milling machine, shown in Figure 3.1, is made by Brodhead & Garrett Company. The following is the company's address:

Brodhead & Garrett Company
4561-T E71 Street Cleveland, OH 44105
(216) 341-0248

The N/C 100 uses AC Motors to move the clamp and the drill. Except for the drill motor, the motors were controlled via a switch box. For example, to run the X motor in the positive direction, the operator must press the X-Plus switch until the clamp reached the desired position. Figure 3.2 shows the switch box. Alternatively, the operator can feed tapes into a slot on the box.

The operation of the N/C 100, by means of a switch box, make it unsuitable for a CMM because the computer cannot keep track of the exact location of the clamp. To illustrate, whenever the computer sends one bit to the CMM to move the clamp, the clamp will move one inch. If the clamp carries a

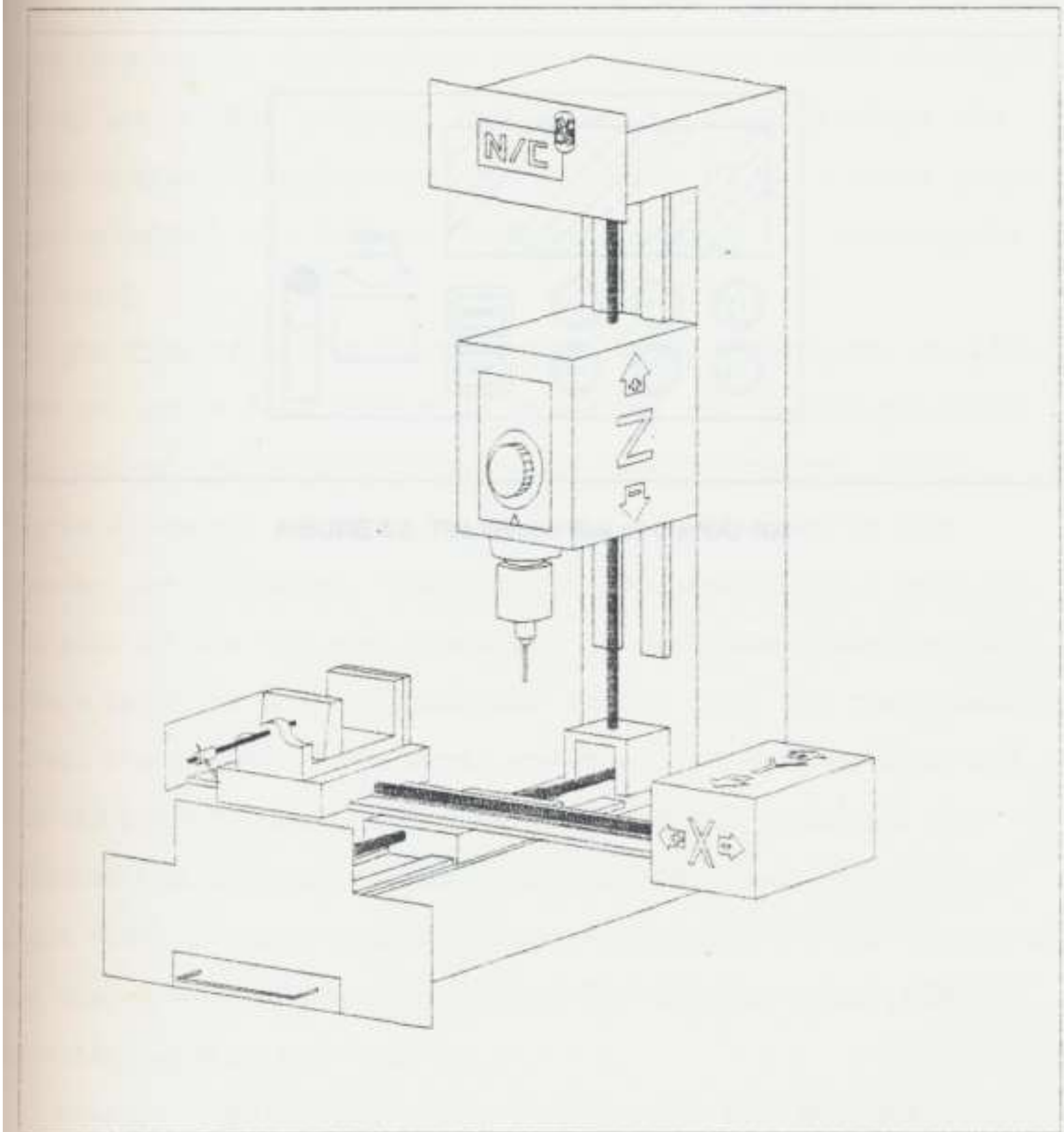


FIGURE 3.1 The N/C 100

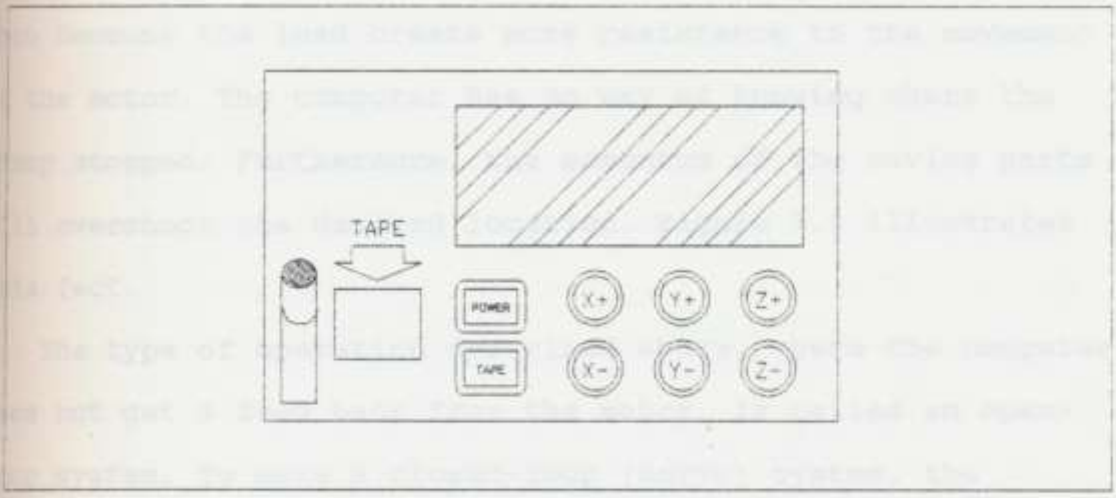


FIGURE 3.2 The Switch Box of the N/C 100

load, the CMM most probably will move the clamp less than one inch because the load create more resistance to the movement of the motor. The computer has no way of knowing where the clamp stopped. Furthermore, the momentum of the moving parts will overshoot the desired location. Figure 3.3 illustrates this fact.

The type of operation described above, where the computer does not get a feed back from the motor, is called an open-loop system. To make a closed-loop (servo) system, the distance covered by the clamp should be reported to the computer at all times, for example, by installing a grid to the side of the CMM and a pointer to the clamp. The pointer always point to a known position in the grid. As the clamp moves, the pointer also moves accordingly. By examining how far the pointer has moved from the original position, the computer can control the movement of the clamp. Figure 3.4 shows this system. However, a closed-loop system is expensive and takes longer time to develop. Due to time constrain, an open-loop system was built.

Using a regular motor in an open-loop system such as in the N/C 100 will yield poor accuracy. Alternatively, stepper motors can be used. By using a stepper motor, one can also get good accuracy for an open-loop system. The CMM developed for this thesis would use stepper motors in an open-loop system because they were available and the lack of funds to

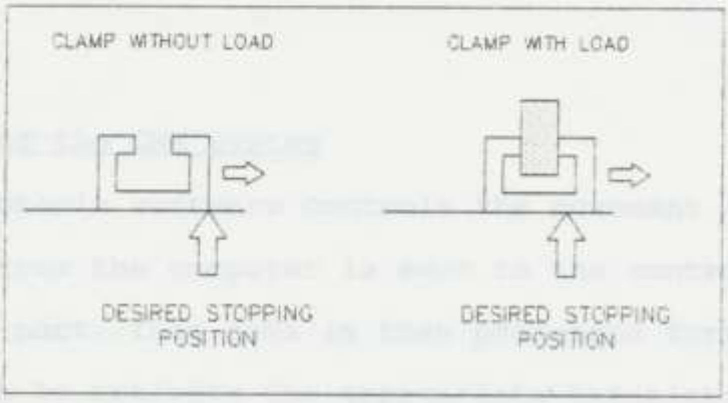


FIGURE 3.3 Limitations of the N/C 100's

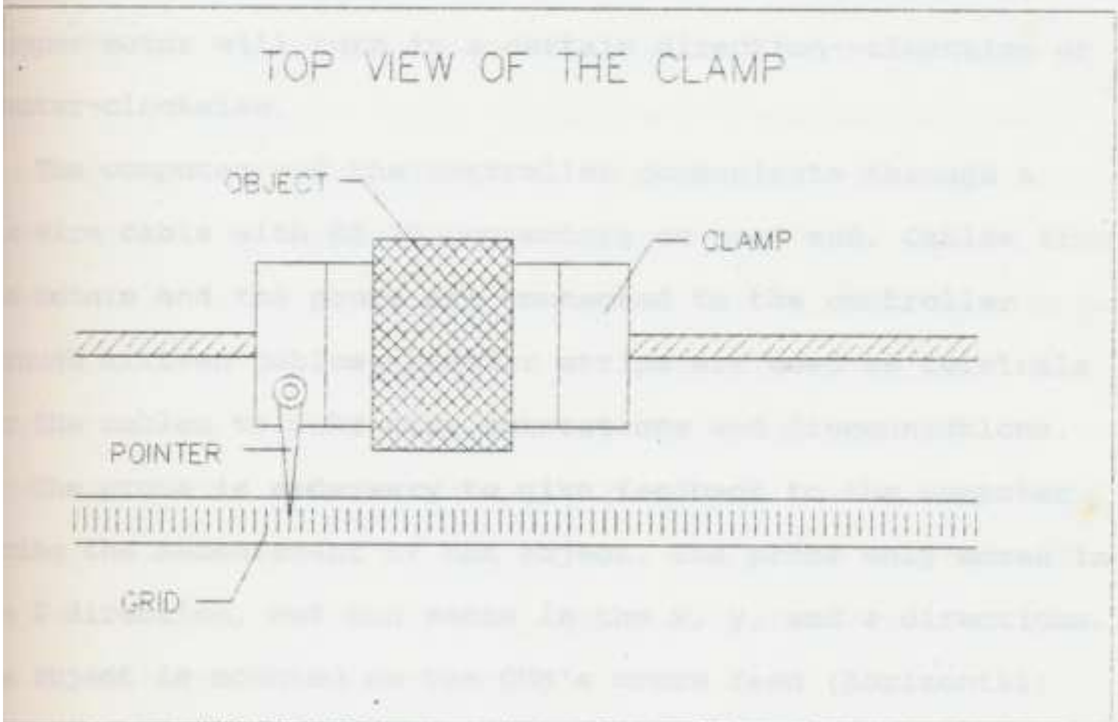


FIGURE 3.4 A servo system using a pointer and a grid

pursue more expensive instrumentation.

The concept of the CMM system

The computer's software controls the movement of the motor. Data from the computer is sent to the controller via the parallel port. This data is then processed further by the logic circuit to activate the appropriate transistor of the motor driver. When the transistor is on, current will flow from the power supply to the designated coil of the desired motor. By energizing the coils in the motor sequentially, the stepper motor will turn in a certain direction--clockwise or counter-clockwise.

The computer and the controller communicate through a six-wire cable with DB 25 connectors on each end. Cables from the motors and the probe are connected to the controller through sixteen cables. Barrier strips are used as terminals for the cables to make easy connections and disconnections.

The probe is necessary to give feedback to the computer during the measurement of the object. The probe only moves in the Z direction, but can sense in the x, y, and z directions. The object is mounted on the CMM's cross feed (horizontal) table and can be moved in the x and y directions.

To check the logic circuit without connecting it to the motor driver, LEDs are used. By passing data to the LEDs, the status of the probe can be monitored. Also, the LEDs would show which coil of the stepper motors is being energized.

3.2 THE HARDWARE

The hardware of the CMM system includes a CMM with a probe and a controller. The controller houses the logic circuit, the motor driver, two power supplies,and the probe's circuit.

Optoisolators are placed between the logic circuit and the motor driver, and between the parallel port and the probe, to protect the logic circuit and the computer from possible power surges. The power surges could be caused by transient energy created by the stepper motors or short circuits. An optoisolator works better than a fuse because an optoisolator allows electricity to flow from the logic circuit to the motor driver but not the other way. In contrast, a fuse allows electricity to flow from either side. Another disadvantage of using fuses is that the reaction time may not be fast enough to stop the power surge from damaging the logic circuit and the computer.

The power supply for the logic and the probe circuits is located on the input side of the optoisolator and its ground is denoted as G1 (see Figure 3.10). The other power supply is used for the motor driver and the probe.

3.2.1 CMM

The steps done to modify the N/C 100 are as follows :

(i) Replace its motors with the stepper motors.

(ii) Install the probe.

(i) Replacing the motors

Before installing the stepper motors to the N/C 100, the AC motors on the N/C 100 had to be removed. The removal was be done easily by unscrewing the motors from the frame. The internal cables in the N/C 100 had to be cut so that the electrical connector which is located in the back could be removed. All parts removed from the N/C 100 had been labeled and put in a clearly marked box. The box and the N/C 100's switch box are kept in the CIM Lab.

There are two types of stepper motors to be installed, two big powerful stepper motors from Fuji Electric Company and a smaller less powerful one. The less powerful motor will be used to move the probe up or down along the z-axis because the energy required to move the probe is less than that required for the horizontal table. The bigger stepper motors are used to move the horizontal table along the y and the x axis. These motors move the clamp or the probe by rotating the drive screws. The drive screws has a pitch of 1/16 inch. The 1.8 degree per step, motor, moves the horizontal table or the probe 1/200 inch per step.

Upon closer examination, the surface of the CMM's body was found to be uneven, thus spacers were required to install the motors. Also, the original bushings could not be used to connect the shafts and the motor's spindle. Therefore, new bushings were made.

(ii) Installing the probe

Because the stepper motor used to move the probe, has low torque, the N/C 100's heavy spindle had to be removed. In its place, a bracket was constructed to hold the probe. The bracket is L-shaped and has a hole for mounting the probe.

The bushings, the spacers, and the bracket were made in the Industrial Process Laboratory.

3.2.2 The Probe

As mentioned in the literature survey, a good commercial probe is very expensive. Any other alternative from using it would be either very complex or inaccurate.

The Probe's Structure

I decided to use a pump needle, used for connecting an air pump to a basketball, and a ballpoint pen's coil as the probe. The resulting because is not expensive and will demonstrate the principles involved. Figure 3.5 shows this probe.

The needle's diameter is 1/8 inch and the coil's is 2/8 inch. After installing the coil to the needle, the distance between the needle and the coil was found to vary from 3/32 to 1/32 inch.

The Probe's Circuit

The probe acts as a switch. Whenever the probe made contact with the object, the coil will touch the needle, causing the circuit to close. The completed circuit provides current to an optoisolator.

This isolation provides insulation and protection to the logic circuitry (see Figure 3.6). Through testing, the optoisolator's resistance output was found to be infinite when no current flows between its input, otherwise it is about 600 Ω. In the following and other calculations, Rx denotes the optoisolator's resistance when it is on.

The value of the R4 and R5 in the probe's circuit is calculated as follows :

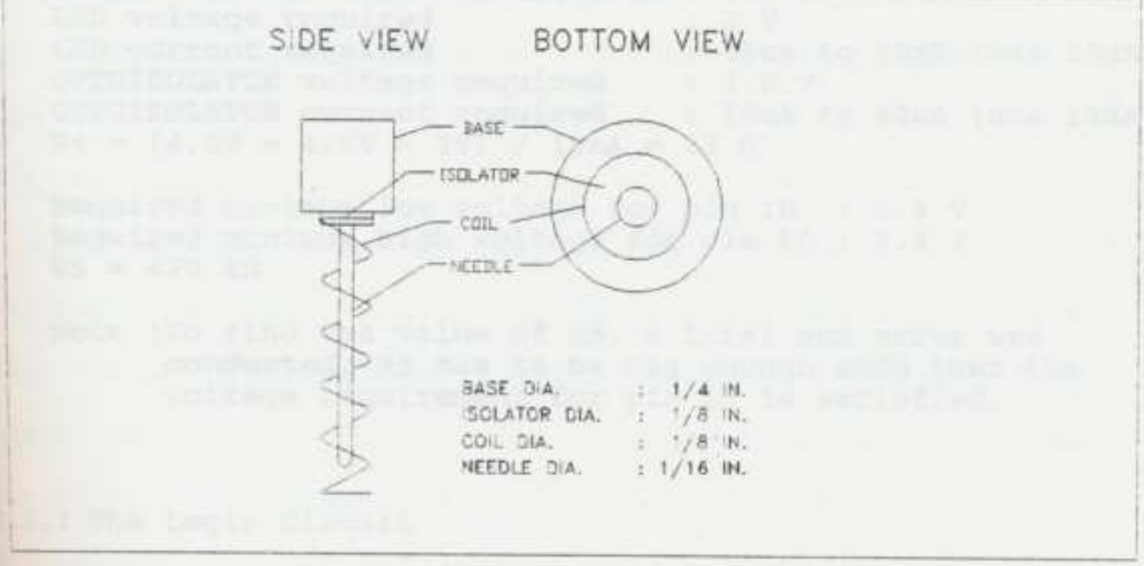


FIGURE 3.5 The Probe

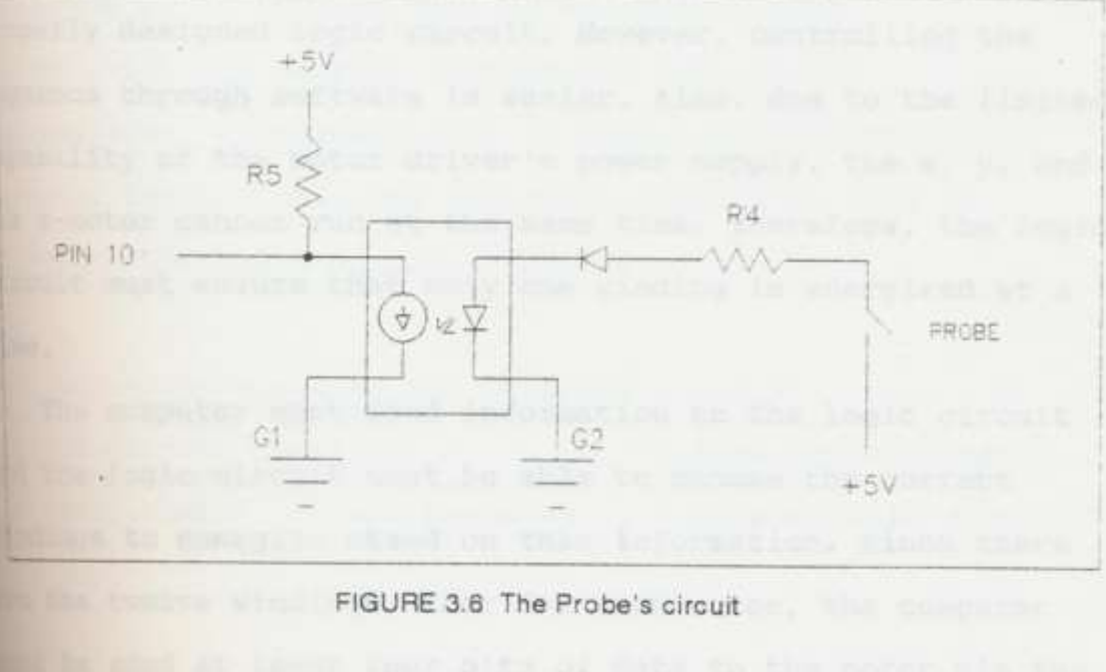


FIGURE 3.6 The Probe's circuit

Output voltage from hex inverter : 4.0 V
LED voltage required : 2 V
LED current required : 10mA to 20mA (use 15mA)
OPTOISOLATOR voltage required : 1.5 V
OPTOISOLATOR current required : 10mA to 60mA (use 15mA)
R4 = (4.0V - 1.5V - 2V) / 15mA = 33 Ω

Required maximum low voltage for pin 10 : 0.8 V
Required minimum high voltage for pin 10 : 3.6 V
R5 = 470 kΩ

Note :To find the value of R5, a trial and error was conducted. R5 has to be big enough such that the voltage requirement for pin 10 is satisfied.

3.2.3 The Logic Circuit

To move the clamp to a desired position, the computer must energize the correct windings of the appropriate motor in the proper sequence. This task can be achieved with a properly designed logic circuit. However, controlling the sequence through software is easier. Also, due to the limited capability of the motor driver's power supply, the x, y, and the z-motor cannot run at the same time. Therefore, the logic circuit must ensure that only one winding is energized at a time.

The computer must send information to the logic circuit and the logic circuit must be able to choose the correct windings to energize based on this information. Since there are the twelve windings, four for each motor, the computer must be send at least four bits of data to the motor via the logic circuit, because three bits can have eight combinations and four bits can have sixteen. Table 3.1 shows these combinations.

The logic circuit consist of twelve four-inputs AND gate. Figure 3.7 shows this circuit. From the TTL Data Book [8], it was found out that this circuitry is available on a single chip called a multiplexer (74154). However, the multiplexer has a low select output so the output must be inverted using hex inverters. Figure 3.8 shows connections for the multiplexer and the hex inverters. The multiplexer accepts 4 input selector bits to get 16 different outputs. Since only the first 12 combinations are required, the last four outputs are not connected. The output of each hex inverter is connected to an LED and then to an optoisolator.

To limit the current through the LED and the optoisolator, a resistor (R1) is placed between the hex inverter and the LED. The following formula is used to calculate the value of the resistor :

Output voltage from hex inverter : 4.0 V
LED voltage required : 2 V
LED current required : 10mA to 20mA (use 15mA)
OPTOISOLATOR voltage required : 1.5 V
OPTOISOLATOR current required : 10mA to 60mA (use 15mA)
$R1 = (4.0\text{V} - 1.5\text{V} - 2\text{V}) / 15\text{mA} = 33\ \Omega$

BITS	COMBINATION	MOTOR	COIL/PHASE
0001	1	X	1
0010	2	X	2
0011	3	X	3
0100	4	X	4
0101	5	Y	1
0110	6	Y	2
0111	7	Y	3
1000	8	Y	4
1001	9	Z	1
1010	10	Z	2
1011	11	Z	3
1100	12	Z	4

TABLE 3.1 The bits combination to energize the correct motor

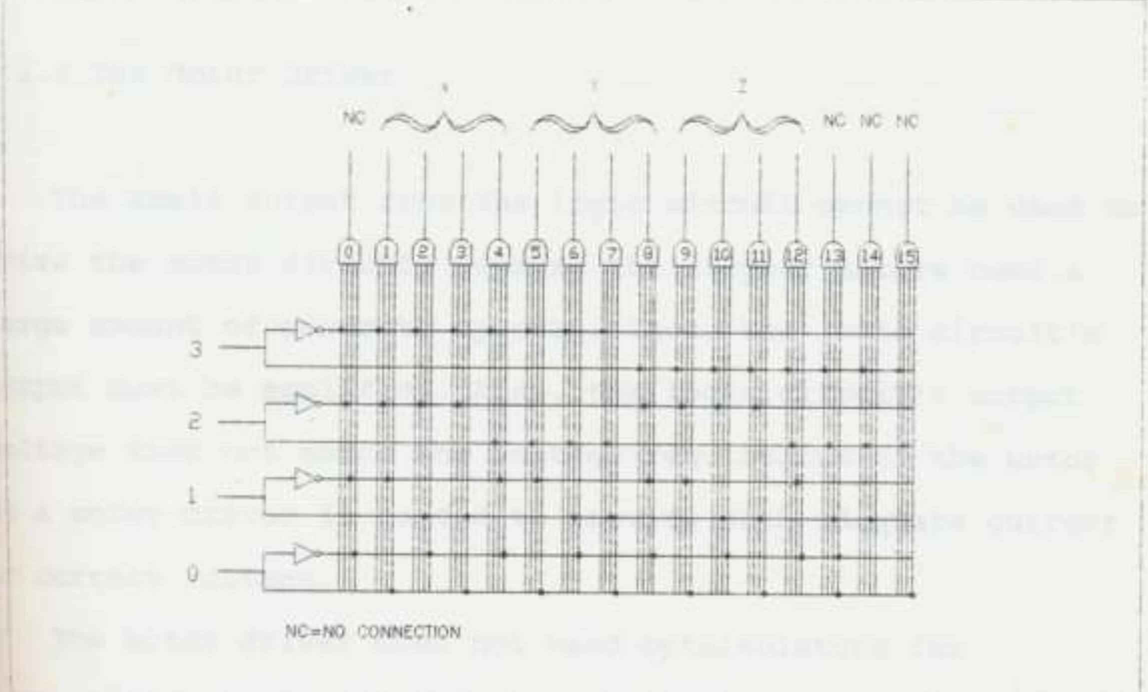


FIGURE 3.7 Logic circuit's diagram

The diagram is for multiplexer on Fig. 3.8

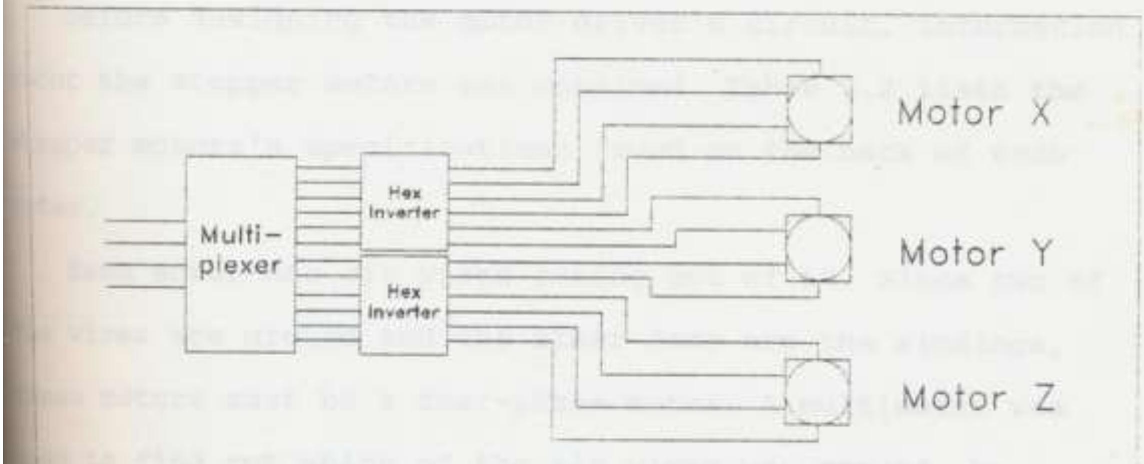


FIGURE 3.8 Logic circuit's chip

3.2.4 The Motor Driver

The small output from the logic circuit cannot be used to drive the motor directly because the stepper motors need a large amount of power to operate. Thus, the logic circuit's output must be amplified. Also, the logic circuit's output voltage does not match the voltage requirement of the motor so a motor driver is needed to provide both adequate current at correct voltage.

The motor driver does not need optoisolators for protection because the driver is not very sensitive to power surge. Also, it is not too expensive to replace if it became damaged.

Before designing the motor driver's circuit, information about the stepper motors was obtained. Table 3.2 lists the stepper motors's specifications found on the back of each motor.

Each motor has six wires coming out of it. Since two of the wires are ground and the other four are the windings, these motors must be a four-phase motor. A multimeter was used to find out which of the six wires was ground, by measuring the resistance between the wires. In each motor, the black and the white cables are ground.

To rotate the rotor clockwise or counter clockwise, the

MOTOR	VOLTAGE	CURRENT	DEGREE PER STEP
Z	12.0V	0.44A	2.0
X,Y	4.5V	1.4A	1.8

TABLE 3.2 Stepper motor's specification

four windings must be energized sequentially. Using a DC Power Supply from the Electronic Laboratory A, the correct sequence can be determined. Table 3.3 shows this sequence.

Figure 3.9 shows the motor driver's circuit. A diode is placed between the motor's common and coil to control the transient effects of the energy generated in the motor. The cables used to connect the transistor's collector to the motors and the transistor's emitter to the ground are much bigger than those for the logic circuit. This is necessary because the current flowing through these wires are high (about 0.5A - 3A).

Ideally, the voltage difference between the collector and the emitter should be about 0.2V, which is the transistor's saturation voltage. The higher the voltage the more energy is dissipated by the transistor and the higher its temperature. This voltage depends on the base resistor's value. Using the following calculation, the value of the resistor can be determined.

For the X and Y motor :

Motor voltage required : 4.5 V (assume 5V)
Motor current required : 1.4 A (provide up to 3A)
Transistor's hf : 2500 (assume 1000)
Voltage between base and emitter : 0.7 V
Current required for transistor's base : 3A / 1000 = 3mA
R3 + Rx = (5V - 0.7V) / 3mA
R3 = 833 Ω

MOTOR	SEQUENCE	DIRECTION
Z	Green,Red/White,Green/White,Red	Counter-Clockwise
Z	Red,Green/White,Red/White,Green	Clockwise
X,Y	Red,Blue/White,Red/White,Blue	Counter-Clockwise
X,Y	Blue,Red/White,Blue/White,Red	Clockwise

TABLE 3.3 Energization sequence of the motor

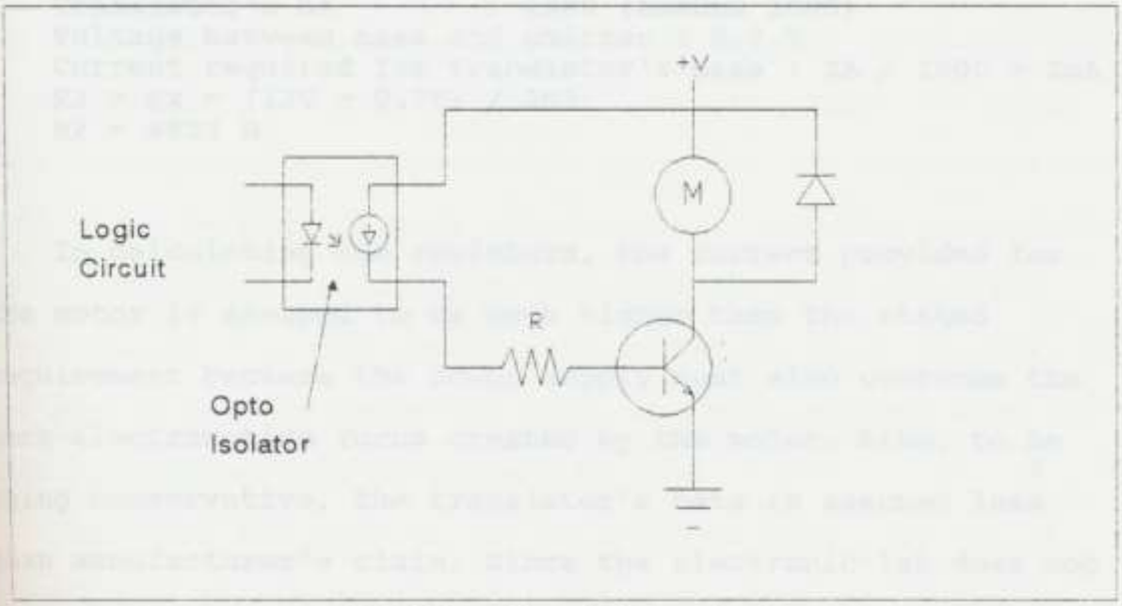


FIGURE 3.9 Motor Driver's circuit

For the Z motor :

Motor voltage required : 12 V
Motor current required : 0.44 A (provide up to 2A)
Transistor's hf : 2500 (assume 1000)
Voltage between base and emitter : 0.7 V
Current required for transistor's base : 2A / 1000 = 2mA
$R2 + Rx = (12V - 0.7V) / 2mA$
$R2 = 6933\ \Omega$

In calculating the resistors, the current provided for the motor is assumed to be much higher than the stated requirement because the power supply must also overcome the back-electromotive force created by the motor. Also, to be being conservative, the transistor's beta is assumed less than manufacturer's claim. Since the electronic lab does not have the necessary equipment to checked such high betas, its value was arbitrarily assumed to be 1000.

To get the ideal voltage, the value of the calculated resistor must obtained through trial and error by increasing or decreasing the resistance slightly until it is obvious that the transistor is in saturation. To ensure that the transistor never gets too hot, heat sinks were attached to the X, and Y motor's transistors. The Z motor's transistors do not require heat sinks because they do not draw as much current as the others.

3.2.4 The Parallel Port

The computer sends data through a parallel port. Since the parallel port is usually used as a printer port, the pin configuration is standard for all IBM PC's. Table 3.4 shows this configuration. Furthermore, Table 3.4 [9] shows that pin 2 to 5 can be used to send the four bits. For the probe, pin 10 (ACKNOWLEDGE) can be used. The computer must check the condition of this pin whenever it tells the motor to move. If the pin is set, it means the probe has made contact with the part and appropriate action can be done.

The other pin such as pin 11 (PRINTER BUSY) and pin 12 (PAPER OUT) cannot be used for the probe because if these pins are set, the computer will stop running until the pins are reset. However, these pins can be useful for pausing the computer. If pin 11 is high then the computer will pause.

3.2.6 The Controller

The combined circuit -- the logic circuit, the motor driver, and the probe's circuit -- is shown in Figure 3.10. These circuits and the power supplies are put in a metal box for neatness and shielding of possible electronic or magnetic

PORT	BIT NUMBERS								FROM	TO	PIN #	FUNCTION
	7	6	5	4	3	2	1	0				
378	x								Computer	Printer	9	Data bit 7
		x							Computer	Printer	8	Data bit 6
			x						Computer	Printer	7	Data bit 5
				x					Computer	Printer	6	Data bit 4
					x				Computer	Printer	5	Data bit 3
						x			Computer	Printer	4	Data bit 2
							x		Computer	Printer	3	Data bit 1
								x	Computer	Printer	2	Data bit 0
379	x								Printer	Computer	11	Busy
		x							Printer	Computer	10	Acknowledge
			x						Printer	Computer	12	Paper Out
				x					Printer	Computer	13	Select
					x				Printer	Computer	15	Error
						x	x	x	Printer	Computer	--	Not used

TABLE 3.4 The IBM printer port I/O usage

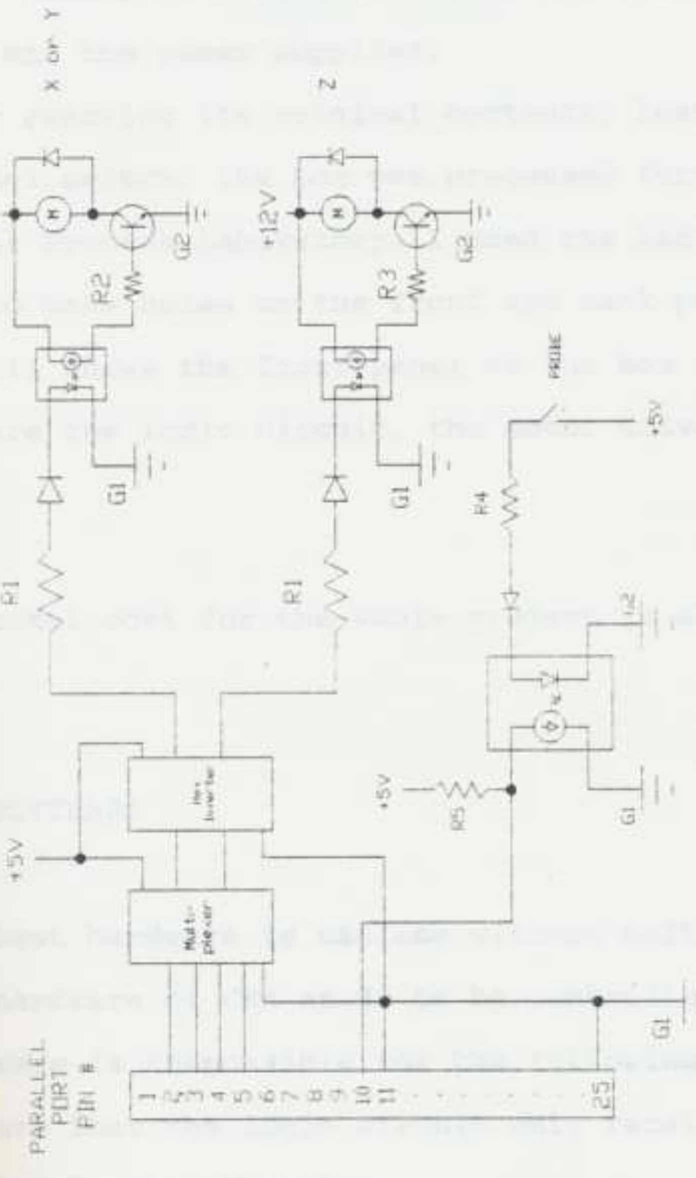


FIGURE 3.10 The electronic circuit inside the controller

interference from outside. Radio Shack sells this type of box for ten dollars. To minimize cost a used metal box was obtained in the USM's stores warehouse. The box does not have any USM's number on it and is big enough to house the circuits and the power supplies.

After removing its original contents, leaving only the front panel switch, the box was processed further in the Industrial Process Laboratory. I used the lab's drill and chipper to make holes on the front and back panel of the box. Figure 3.11 shows the front panel of the box and Figure 3.12 shows where the logic circuit, the motor driver, etc. are located.

The total cost for the whole project is shown in Appendix A.

3.3 THE SOFTWARE

The best hardware is useless without software to control it. The hardware of CMM needs to be controlled by software. The software is responsible for the following :

1. Ensure that the logic circuit only receive integer numbers- zero to twelve.
2. Energize the correct coil of the appropriate motor.
3. Cut off power to the stepper motors when they are not

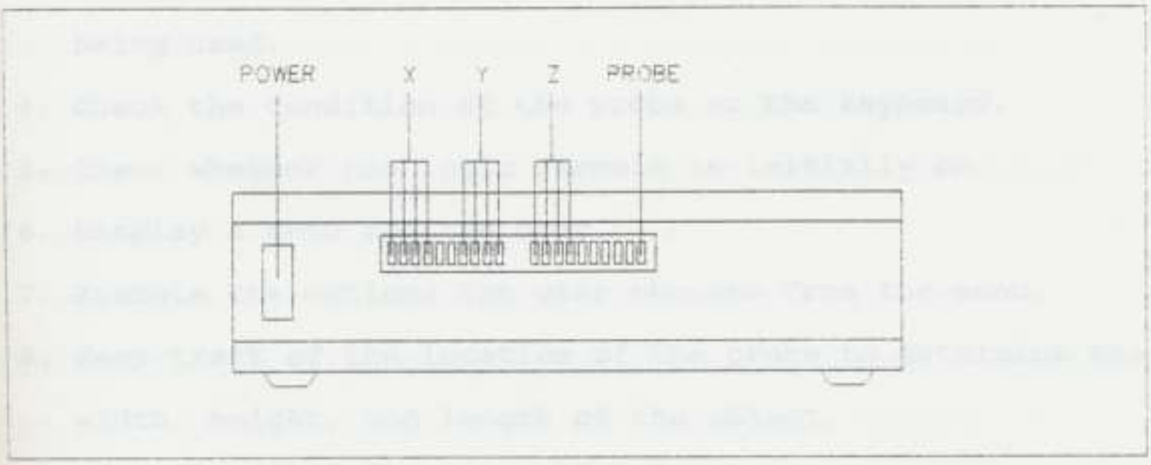


FIGURE 3.11 The Controller's front panel

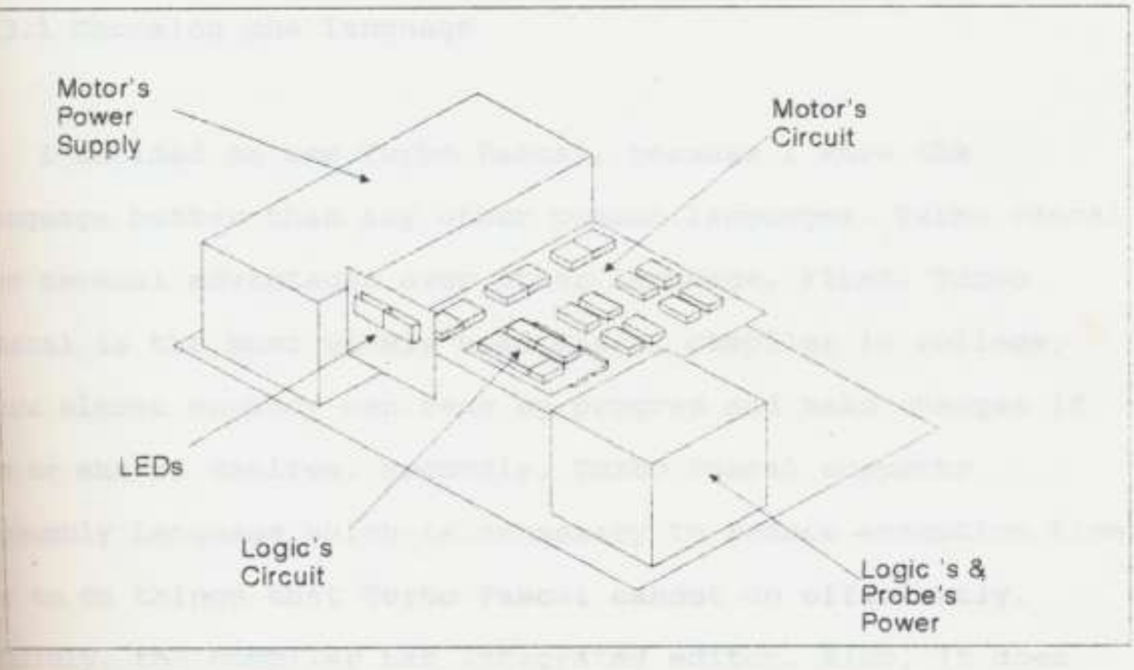


FIGURE 3.12 Inside the controller

being used.

4. Check the condition of the probe or the keyboard.
5. Check whether the logic circuit is initially on.
6. Display a menu for the user.
7. Execute the options the user chooses from the menu.
8. Keep track of the location of the probe to determine the width, height, and length of the object.
9. Check the user's input and trap any errors.

3.3.1 Choosing the language

I decided to use Turbo Pascal, because I know the language better than any other common languages. Turbo Pascal has several advantages over other language. First, Turbo Pascal is the most widely used Pascal compiler in college, thus almost anybody can read my program and make changes if he or she so desires. Secondly, Turbo Pascal supports Assembly Language which is necessary to reduce execution time or to do things that Turbo Pascal cannot do efficiently. Thirdly, the compiler has integrated editor. Also, it does not require a hard disk.

I used Turbo Pascal version 4.0, which I had purchased directly from Borland, instead of version 3.0. The reason is because the newer version supports EGA (Enhanced Graphics

Adapter) and includes a predefined register variables, eliminating the need to declare the microprocessor's registers and the flags. Also, the newer version is faster and generates smaller executable file.

The Turbo Pascal 4.0 Owners Handbook [10], Sutty's Programmer's Guide to the EGA/VGA [11], and Duncan's IBM ROM BIOS [12] and MS DOS Functions [13] were very helpful in aiding the development of the software.

3.3.2 The Program

The program consists of one main program and 30 procedures. Global variable declarations and procedures are written as include files which means only the name of the files are included in the main program. All those procedures are important but not all of them are complicated, thus only the specially important procedures will be fully discussed. Appendix B shows the complete list of the source code.

1. Procedure Keywait

   Consumes a character in the keyboard buffer or waits until one is available.

2. Procedure First Message

Displays the first opening screen.

3. Procedure Move Plotter

Move pictures to form the letters "CMM".

4. Procedure Blank Screen

Fill the screen with white block characters.

5. Procedure Scroll

Scroll the screen pixel by pixel. This procedure is taken from Sutty [11].

6. Procedure Hide Cursor

Hide the screen cursor.

7. Procedure Second Message

Displays the second opening screen and scrolls the messages.

8. Procedure Send Data

Sends data to the logic circuit through parallel port. At first, I tried to send data by sending them to the port's address such as port 378(hex) for lpt1, but this method only works in some computers. The problem does not lie with the computer, rather it lies on the parallel port card. Some parallel cards use a different port address to send data to the printer and use port 378 for something else. To avoid compatibility problems, I used MS-DOS interrupt 17(hex) function 0, which is used to send characters to printer. This interrupt will find the right port number regardless.

9. Procedure Power Off

Cuts off power to the stepper motors when not in use.

10. Procedure Step

Selects the requested motor. This procedure determines the correct character to be sent to the logic circuit by calculating the index of X, Y, or Z array, and increment or decrement the index according to the direction. Direction can be 1 or -1. For example, array Y consist of 5,6,7,8, thus Y[1]:=5, Y[2]:=6, Y[3]:=7, and Y[4]:=8. The following formula will make sure that the index of Y will be between 1 and 4 so that the characters sent to the logic circuit will be 5,6,7,8,5,6,7,... or 8,7,6,5,8,7,6,.... :

Index = (Index + direction + 4) MOD 4

11. Procedure Check Probe

Interrupt 17(hex) function 2, is used to get the printer status. This interrupt will return the printer's status in register AL. Since I am only concerned with the status of bit 6 (ACKNOWLEDGE), I masked out the other bits and check the result. If bit 6 is set, it means the probe has made a contact with the object.

12. Procedure Check Keyboard

This procedure is functionaly similar to procedure Check Probe. The difference is that if this procedure is used, the computer will check the keyboard status instead of the probe. Pressing a key is the same as if the probe has hit an object.

This procedure is useful for locating bugs in the program because simulating the CMM on the screen is faster and safer than the real thing. This procedure and procedure Check Probe have delay statements in them because the computer is fast. Without the delay, the keyboard's and the probe's status may not be checked properly.

Note : The program can use either procedure Check Keyboard or Check Probe, not both of them.

13. Procedure X_Pixel

Turns on a pixel on the graphic screen when the probe is moving in the x direction.

14. Procedure Y_Pixel

Turns on a pixel on the graphic screen when the probe is moving in the y direction.

15. Procedure X_Back

Since the program pauses when the probe made contact with the object, this procedure is necessary to move the probe to break contact, so that the probe can move away from the object, thus making it possible for the program to continue.

16. Procedure Y_Back

Functionally the same as procedure X_Back.

17. Procedure Z_Back

Functionally the same as procedure X_Back.

18. Procedure X_Move

Moves the probe in the plus or minus X direction as far as desired.

19.Procedure Y_Move

Functionally the same as procedure X_Move.

20.Procedure Z_Move

Functionally the same as procedure X_Move.

21.Procedure Check Height

First, the procedure will compute the location of the height check points. Secondly, the procedure will bring the probe up to the first check point and start checking until the last point has been checked. Thirdly, the procedure will bring the probe to its home position.

22.Procedure Graph Simulation

Tool path Algorithm. See next section.

23.Procedure Readin

To read number of rows and columns while in graphics mode. In Turbo Pascal 4.0, the READ statement will echo the input in textmode even while the screen is in graphics mode. To get around this problem, I wrote my own procedure to get a maximum of two digits from the keyboard and echo them to the graphic screen in the proper right mode.

24.Procedure Set Screen

Switches to graphics mode and draws border lines. Also, the procedure calls procedure Readin to prompt the user for the number of row and column. Afterward, this procedure will call procedure Graph Simulation to begin the measurement process. The user can abort the process any time by pressing the ESC key. However, the response may not be immediate because delays programmed into procedure Check Keyboard and procedure Check Keyboard.

25.Procedure Check Machine

To check whether or not the CMM has been turned on.

26 Procedure Set Home Position

When invoked, this procedure enables the user to move the probe using the keyboard. The left and right arrows controls the X motor. The up and down arrows control the Y motor. The Page Up and Page Down keys control the Z motor.

27.Procedure Save

To save the result of the new measurement to a file. The user will be prompted to enter the file name.

28. Procedure Compare

To compare the result of the measurement of the new object to those from a file. If the number of rows and columns of both objects are not equal, the unavailable data will be left blank. For example, the new object has six checking points while the older object has eight. The procedure will display all eight points and left two blank spaces for the new object.

29. Procedure Show

To display the result of the measurement of the new object.

30. Procedure Menu

This procedure will display the menu in the form of a window. The user can select the options by pressing the up or down arrow keys and hitting the enter key when he or she has highlighted the desired option.

This procedure calls the following procedures : Set Home Position, Set Screen, Show, Compare, and Save. Also, this procedure includes code to select the parallel port : lpt1, lpt2, and lpt3.

3.3.3 The Menu

The program is user friendly. Upon running the program, the computer will display messages and a menu, then the computer will wait until the user has picked his or her selection. The following options are available from the menu.

1. Measure new object.
2. Display Result.
3. Compare result with those in data base (other file).
4. Save result to a file.
5. Quit.

Option 1 will initiate the measurement process. The computer will check if the CMM is turned on and promptly ask the user to turn it on if he or she has not already done so. Next, the user must move the probe to its home position using the arrow keys and the page up/down keys, and press enter when done. Afterward, the user must enter how many rows and columns of check points are to be used for checking height. To minimize memory usage, the maximum number of points is 7 X 7, which is 49 points.

Option 2 will display the measurement's result. However, if the number of check points are greater than 12 the screen will scroll up, thus hiding the top portion of the screen.

Option 3 will compare the result to other measurement from a file. In case the height's check point of both measurement differ, the unavailable data will be left blank on the screen. As in option 2, the screen will scroll up if the number of points are greater than 12. It should be noted that the input file name must exist. Otherwise the user will get a run time error.

Option 4 will save the result to a file in the following format :

```
Width  Length
Number of Row    Number of Column
(Height Coordinate X) (Coordinate Y) (Height[1])
.
.
.
(Height Coordinate X) (Coordinate Y) (Height[row*colom])
```

3.3.4 Tool Path Algorithm

Measuring different shapes requires different algorithm. Due to time constraints, only one algorithm was written for this project. The algorithm, which is in procedure Graph Simulation, is for measuring a simple rectangular object.

Before attempting to run the measurement process, the user must do the two steps. First, the user must move the probe to its home position as shown in Figure 3.13. Secondly, the user has to enter the number of the height's checking points. The maximum number of checking points is 49 which is 7 by 7.

After the user has accomplished these steps, the program will call procedure Graph Simulation to do the measurement. The user can abort the process at any time by pressing the ESC key. The algorithm consist of two sub-algorithms which work consecutively:

(i) Find the width and the length.
(ii) Find the height.

<u>(i) Find the width and the length of the object</u>

(See Figure 3.14, frame no.1 - 4)

1. Find the lower boundary (bottom Y). The probe will move in the +Y direction until it makes contact with the object or far enough such that it can be assumed that the object is found.
2. When it contact has been made, the value of the Y coordinate is stored (frame no.1).
3. The probe will move away from the object as long as the probe is still in contact with the object, then it will move even further for a short distance before moving to the next possible location (frame no.2).
4. The probe has to find at least one encounter point with

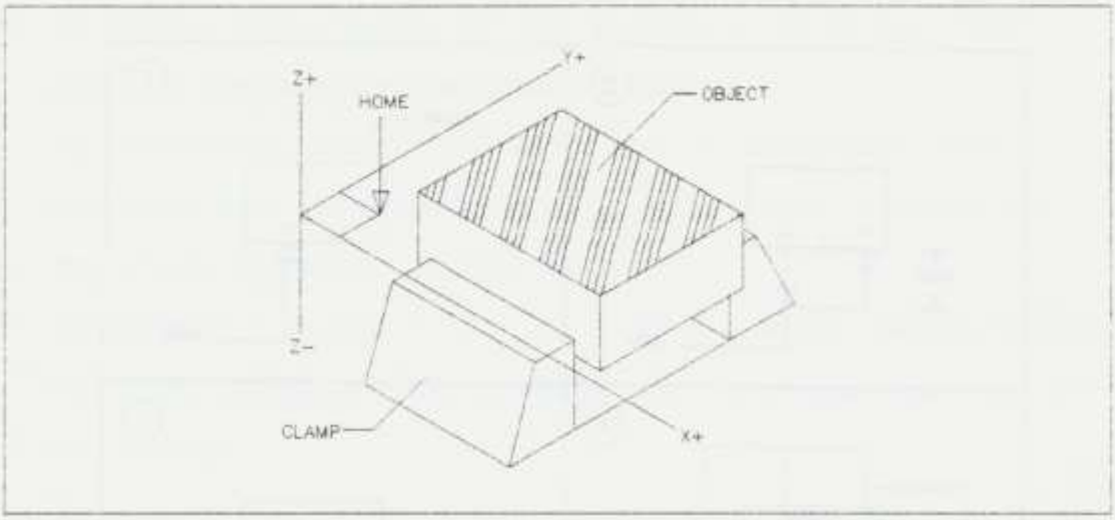


FIGURE 3.13 Home position of the probe

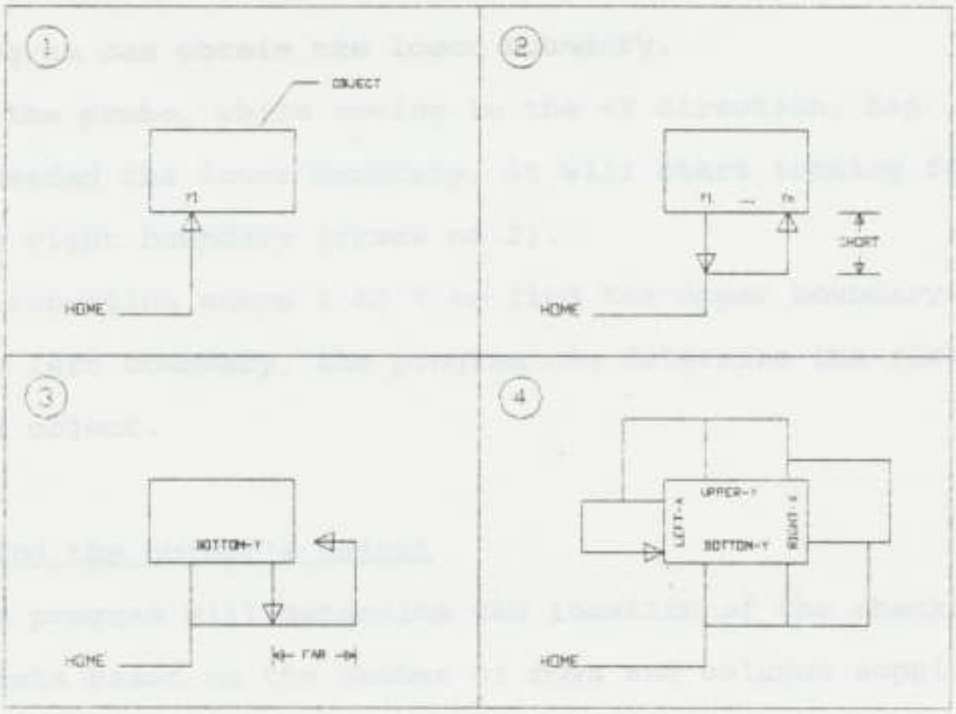


FIGURE 3.14 Tool path to find the object's width and length

the object. Otherwise, the program will fail.

5. By taking the average of the encounter point(s), the program can obtain the lower boundary.
6. If the probe, while moving in the +Y direction, has exceeded the lower boundary, it will start looking for the right boundary (frame no.3).
7. By repeating steps 1 to 7 to find the upper boundary and the left boundary, the program can determine the size of the object.

(ii) Find the object's height

1. The program will determine the location of the checking points based on the number of rows and columns supplied by the user and store the result in an array. To minimize the toolpath, the program will not check the points from array[1] to array[n], because that way will make the probe follow a sawtooth path, which takes a lot of time. Instead, it will check the points row wise as shown in Figure 3.15.
2. The program will raise the probe until it is higher than the object, then it will start checking the points row wise.
3. After all points have been checked, the probe will return to its home position.

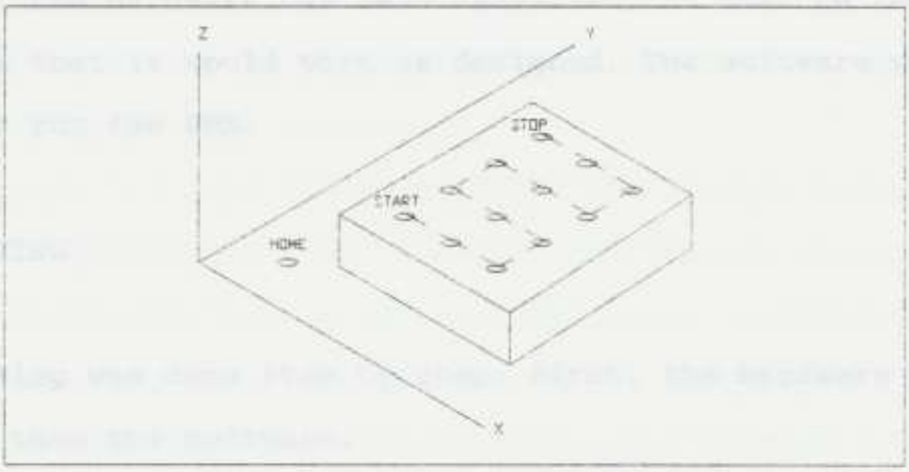


FIGURE 3.15 Tool path to find the object's height

CHAPTER 4 : SYSTEM EVALUATION

After the hardware has been assembled, it must be tested to ensure that it would work as designed. The software was also tested to run the CMM.

4.1 CHECKING

Checking was done step by step. First, the hardware was checked, then the software.

Testing the hardware

Before the test was conducted, all connections for the motor were checked.

The X motor was the first motor tested. Upon first trial, the motor driver was able to run the motor, indicating the design is correct. The voltage between the transistor's emitter and collector is 0.89 Volt which is a little bit too far from the ideal 0.2 Volt. However, the transistor never seems to get too hot to touch, so the value of the base resistors does not need to be changed.

Because the power supply for the motor is a switching type with two different output voltages (5 Volts and 12 Volts), the next motor to be tested should be the Z motor.

This is because all of the switching power supply's output must always be loaded. Otherwise, the power supply will not operate properly. The X and Y motors require 4.5 Volt and the Z motor requires 12 Volts. The 5 Volt output from the power supply does not have to be stepped down to 4.5 Volts because the voltage difference is small.

At first, 1.5 Amps was provided to the Z motor because the motor requires 1.4 Amps. However, the Z motor was able to lower the probe but unable to raise it. After reducing the base resistor's value, thus increasing the current to 2 Amps, the Z motor was able to raise the probe. The voltage between the collector and the emmitter was 0.59 Volt.

The connection for the Y motor is identical to the X motor because the motors are identical. Furthermore, the voltage between the collector and the emitter is the same (0.89 Volt).

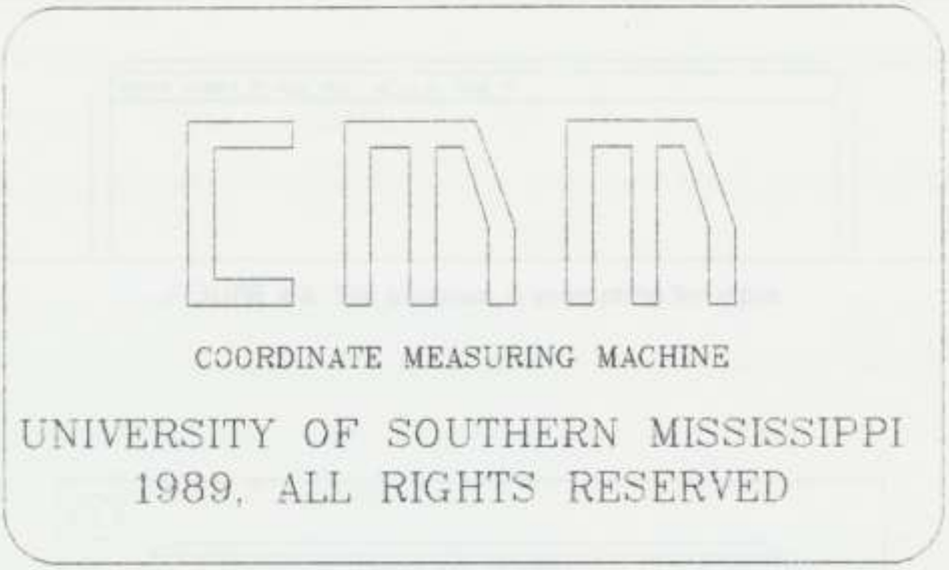
Testing the software

Initially, the program was supposed to move the probe away from the object as soon as the probe made contact. The program knows when this happens because the program checks the probe's status with every step of the motor. The problem is that checking procedures do not allow the program to continue executing as long as the probe is in contact with the object. This problem was solved by forcing the probe to move away from the object without checking the probe's status.

4.2 DRY-RUN

After checking the hardware and software, a dry-run was performed to find out if the project works as designed. The following were some of the important steps in running the program :

1. After typing "MASTER", the computer displayed the first opening screen as shown in Figure 4.1. The screen showed the title of the progeam.
2. Next, the program displayed the second screen and continued to the menu. Figure 4.2 shows the menu. By pressing the up and down arrow keys, an option of the menu could be selected. The default selection is "Measure a new object."
3. If the user had selected the default selection, program would asked the user to set the probe to its home position.
4. The program prompted the user to enter the row and colom of the height's checking point. Figure 4.3 shows the program prompting for the number of row.
5. Figure 4.4, frames no. 1 and 2, shows the program



CMM

COORDINATE MEASURING MACHINE

UNIVERSITY OF SOUTHERN MISSISSIPPI
1989, ALL RIGHTS RESERVED

FIGURE 4.1 Opening screen of the program

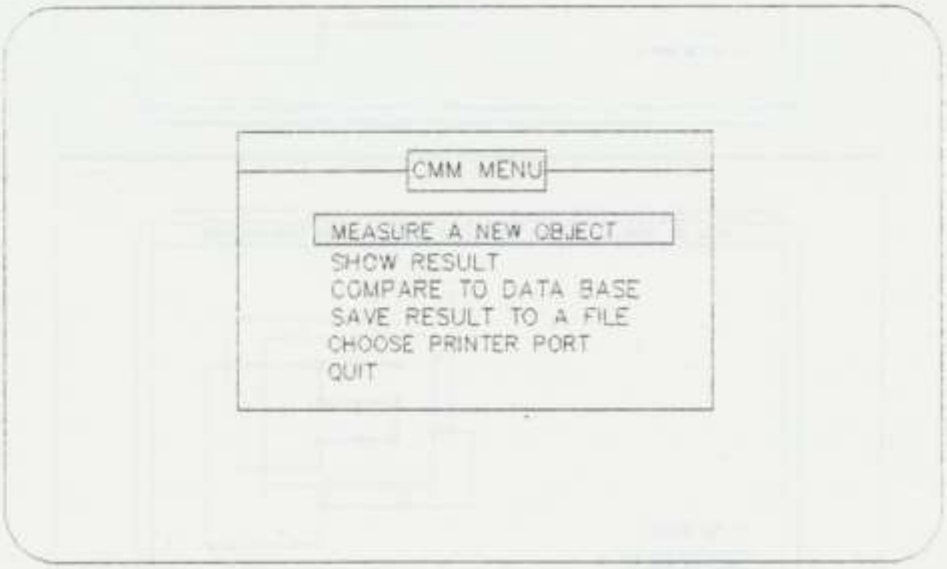
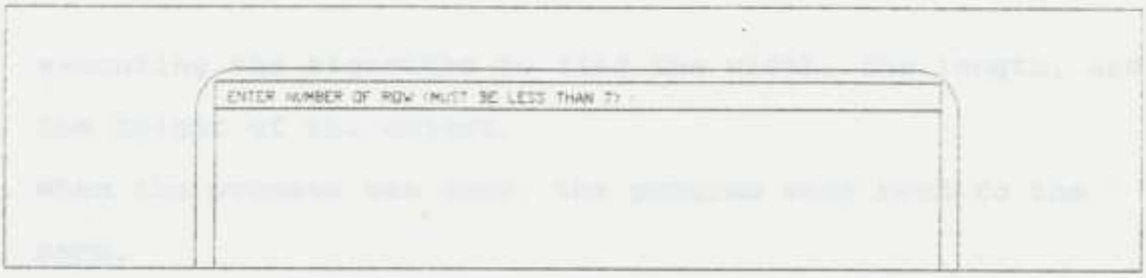
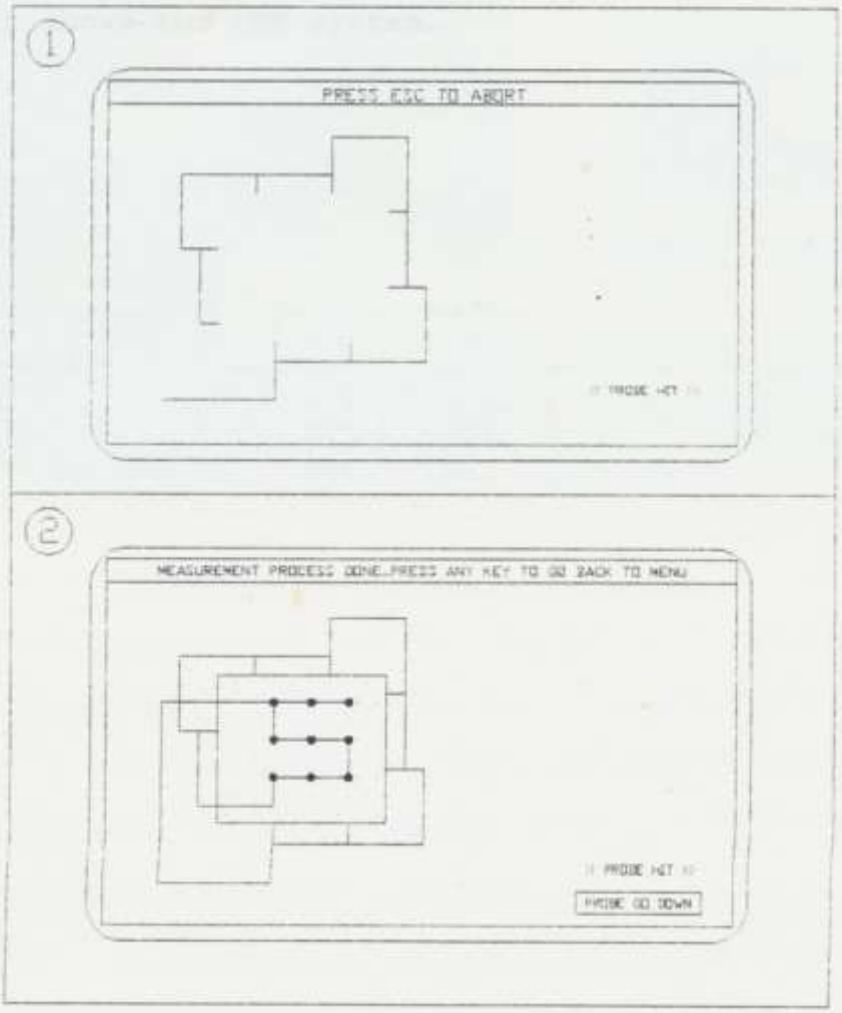


FIGURE 4.2 The program's menu



ENTER NUMBER OF ROW (MUST BE LESS THAN 7) :

FIGURE 4.3 The program is prompting for input



PRESS ESC TO ABORT

<< PROBE HIT >>

MEASUREMENT PROCESS DONE..PRESS ANY KEY TO GO BACK TO MENU

<< PROBE HIT >>

PROBE GO DOWN

FIGURE 4.4 The measurement process

executing the algorithm to find the width, the length, and the height of the object.

6. When the process was done, the program went back to the menu.

At this point the hardware and the software has been tested thoroughly and they turn out to be working well. Figure 4.5 shows the CMM system.

FIGURE 4.5 The photograph of the CMM

CHAPTER 5 : DISCUSSION & CONCLUSION

Developing a CMM is not a trivial task, especially if the job involves the use of a computer to control it. There are many difficulties and problems that must be solved to make the computer controlled CMM work and usable. However, this thesis proved that such a task can be accomplished. The CMM developed in this thesis is capable of the following requirements of a basic computer controlled CMM :

(i) Complete control of the stepper motors and the probe.
(ii) Perform measurement under the computer's control.
(iii) Simulate the measurement process on the computer's screen so that the user can monitor its operation.
(iv) The user can abort the measurement process anytime.
(v) Display and save the result.
(vi) Compare the result to a file.

As an added feature, the software is portable and will allow the user to select the parallel port. The hardware is fully protected from power surges that can damage the computer and the hardware itself. Also, the box where the hardware is located, is made of metallic material which protects it from electronic or magnetic noise. Furthermore, the controller has LEDs for displaying which coil is being energized and whether the probe is making contact with the part.

With all these features, the CMM will be a valuable new piece of equipment for the CIM Lab.

5.1 DESIGN LIMITATION

For every problem solved, there will be another problem to ponder. Due to time and budget constrain, the CMM developed for this thesis has some limitations.

Because the performance of a CMM depends on its limitations, it is appropriate to discuss this matter.

The most obvious limitation of the CMM is its deficiency in accuracy. Even though the CMM cannot be fully tested yet for its accuracy, its potential performance can be predicted by examining its components. These components are :

(i) The probe
(ii) The workholding device
(iii) The motor
(iv) The software

(i) The probe

A high quality probe is expensive. To lower the cost, a low cost probe has been designed. However, the probe has the following limitations which reduce its accuracy.

- It is difficult to center the needle inside the coil.

- As the probe is raised up or down, the coil moves in relation to the needle because the wire which is soldered to the coil is heavy enough to create resistance.
- The bending of the coil may cause the probe to make contact with the object before the probe actually touches the object.
- The needle may bend a little bit when the probe makes contact with the object.
- The size of the probe is not suitable to measure narrow cavities.
- The probe may not be perfectly normal to the xy plane.

(ii) The workholding device

Originally, the N/C 100 came with a screw clamp. This clamp is not suitable for CMM for the following reasons:

- The screw clamp limits the measurable section of the object. Part of the object which is held by the clamp cannot be measured. A solution to this problem is to take measurement of the object for different orientation. However, this is the traditional method which CMM tries to avoid.
- If the object is such that the clamp cannot hold it firmly, the CMM will lose its of precision and repeatability.

(iii) The motor

The motor is barely powerful enough to move the table and the probe, thus limiting the weight of the probe and the object to minimum. Furthermore, since the CMM is an open-loop system, the computer cannot accurately monitor the location of the probe, especially when the motors are not running smoothly. Therefore, CMM may cause erroneous measurement.

(iv) The software

The not so obvious limitation is that the CMM will need different algorithms to measure different objects. Even when the shape of the object is known, it is usually difficult to write algorithm that can guide the probe along the object, especially if the object has an irregular shape. The algorithm developed in this thesis is limited to measuring a rectangular object such as a box.

5.2 RECOMMENDATION

The CMM still has a lot of room for improvement. There are several ways to improve the CMM. The following tasks are recommended for :

(i) Probe

(ii) Workholding device
(iii) Controlling the motor
(iv) Software

(i) Probe

The probe must be modified or redesigned. Making the probe shorter can increase its accuracy by decreasing the bending effect of the coil. However, it will reduce its capability to measure deep, narrow crevices. Using a narrower coil for the probe will also minimize the bending effect.

There are many other types of probe that can be designed to replace the current probe. For example, the probe can be replaced by light system similar to the laser system. The light beam is focused on certain spot and a photo cell can read that spot. If the photo cell misses the spot, it means that the object's edge or surface has changed.

(ii) Workholding device

Find another way to hold the object. Some companies offer vacuum systems which could be used to hold the object. This system is probably the best replacement for the the clamp.

(iii) Motor system

Designing a servo system for the motor with electronic or mechanical damping will improve the CMM's performance. For example, installing a shaft encoder to monitor the rotation of the motor and using a stepper motor controller chip to control its acceleration and deceleration will enable the computer to move the probe or the clamp with much greater precision. As the result, the accuracy of the CMM will be improved.

Try different resistors to make the transistor run cooler. The ideal voltage between its collector and emitter should be about 0.2 V. To obtain this ideal voltage or close to it, the resistance at the base can be found by trial and error.

Buy a bigger power supply for the motors. A bigger power supply has at least two advantages. First, the power supply will be able to run all three motors simultaneously. Secondly, it will run cooler because it does not have to work to its limit.

Install an extra switch so that the power supply for the motor drivers can be turned on independently from the other power supply. This is a safe way to experiment with the program without involving the stepper motors.

(iv) Software

The software is written such that the real probe follows the probe's path on the screen. One pixel corresponds to one motor step. If the steps required to measure the object are greater than the screen's limit, only part of the probe's path can be displayed on the screen. This limitation can be overcome by rewriting the program such that the real probe's path will simulate the real probe's path. The program will need a conversion factor to convert the number of steps to their corresponding number of pixels. Also, the measurement unit is number of steps so a conversion factor is required to convert them to inches. The factor can be determined by observing how far each motor travels per step. It should be noted that for the same number of steps, the motor does not necessarily move the same distance for different directions.

The program does not respond fast enough to the ESC key to stop the process. If the computer sends data to the motor too fast, the motor will not move at all, thus the program must slow down its execution by using delay statements. However, these delay statements decrease the response time. Therefore, the best delay must be determined.

Use pin 11 (BUSY) of the parallel port to hardware pause the measurement process. This will enable the software to pause the process faster than checking the keyboard. The connection in the parallel cable has been made, so only a simple momentary switch is required to connect the pin to a 5 Volt power supply.

There are untrapped errors that can cause a run time error. For example, if a user wants to compare the new measurement to those from a file, the program will fail if he or she entered an invalid file name. One solution is to control DOS function directly using interrupt routines.

5.3 CONCLUSION

The CMM developed for this thesis consist of a table, where a screw-clamp to hold the part is located, and a movable bracket which holds the probe. The table can be moved in two directions, corresponding to the x and y coordinate. The probe can only move up or down.

The total cost to develop this microprocessor controlled CMM was $ 89.91. (See Appendix A)

The CMM is able to measure the width and the length of an object. Given more powerful motors, the CMM would be able to measure the height of the object as well. The objective of this thesis, developing a microprocessor controlled CMM, within limited budget and time, has been reached.

BIBLIOGRAPHY

[1] Lavole, Ron. "Shopping Intelligently for CMMs", Manufacturing Engineering, April 1989 : 67.

[2] "CMM Technology improves." Automation, April 1989 : 17.

[3] Doyle, Lawrence E. et.al. Manufacturing Process and Materials for Engineers, New Jersey : Prentice-Hall, 1985 : 437.

[4] "Made to Measure." Manufacturing Engineering, June 1989 : 25.

[5] Kennedy, Clifford W et.al., Inspection and Gaging, New York : Industrial Press Inc., 1977 : 478.

[6] Giacomo, Paul. "A Stepping Motor Primer," BYTE, Vol.4 No. 2 February 1979 : 90. Vol.4 No. 3 March 1979 : 142.

[7] Metra Byte Corporation. Product Catalog, Volume 20, 1989 : 99.

[8] Texas Instrument Incorporated. The TTL Data Book, Volume 2, 1985.

[9] International Business Machine Corporation. IBM Technical Reference Options and Adapters, Volume 2, 1988 : Printer Adapter 3 to 7.

[10] Borland International. Turbo Pascal 4.0 Owner's Handbook, 1987.

[11] Sutty, George J. et.al. Programmer's guide to the EGA/VGA, New York : Brady Book's, 1988.

[12] Duncan, Ray. IBM ROM BIOS, Washington: Microsoft Press, 1988.

[13] Duncan, Ray. MS DOS Functions, Washington : Microsoft Press, 1988.

[14] Ranky, Paul G. Computer Integrated Manufacturing, United Kingdom : Prentice-Hall International Ltd, 1986 : 328.

[15] Hitomi, K. Manufacturing Systems Engineering, London : Taylor & Francis Ltd, 1979 : 241.

[16] Griffith, Gary. Quality Technician's Handbook, New York : John Wiley & Sons Inc., 1986 : 247.

[17] Groover, Mikell P. CAD/CAM : Computer Aided Design and Manufacturing, Engelewood Cliffs, NJ : Prentice-Hall, 1984 : 425.

[18] Zink, Joseph H. "Closing the CIM Loop with CMM", Automation, January 1989 : 49.

[19] Fix, Stephen L., and Gerald L. Frank. "Process Control : Emerging Role for CMM", Automation, April 1989 : 30.

[20] Sargent III, Murray, and Richard L. Shoemaker. The IBM PC from the inside out, Menlo Park, CA : Addison Wesley Publishing Company Incorporated, 1986.