# Indigenization of Technology – Design and Fabrication of Demonstration Model of a 3-axes CNC Milling Machine Interfaced with a Personal Computer Using Pro Engineer

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## Abstract

The aim of this research paper is to study the existing CNC technologies and use this knowledge to indigenously design and fabricate a demonstration model of a 3-axes CNC milling machine. The research also involves the study and use of the latest CAD, CAM techniques, Design of Control and Interfacing of a Personal Computer (PC) with this Milling Machine. In addition, experiments are also carried out to confirm the design parameters. An attempt has been made in this design and experimental project to use Computer Aided Engineering (CAE) environment using Pro/Engineer tools and techniques to create 3-D models and carry out Computer Aided Manufacturing (CAM). The project involves the use of TurboCNC as the control software for the prototype CNC milling machine. For interfacing and control with a PC, 8051 Micro Controller and Assembly programming based drive circuitry has been designed and used. This research will push forward the knowledge boundary of design of CNC machines [1].

In Pakistani industry, there is a growing demand for more precised, flexible and high production technology. For this purpose expensive CNC machines are being imported. Hence, it is the need of time to develop indigenous CNC machines in Pakistan.

**Key Words:** 3-Axes, CNC Manufacturing, CAD, CAM, Post Processing, Control Software, Indigenization

## Introduction

Manufacturing is the backbone of Mechanical and Manufacturing Engineering and has major contribution in the national economic growth. Manufacturing time, precision, quality, flexibility and productivity are the major factors of competitiveness in Manufacturing Industry. Conventional manufacturing processes cannot meet these challenging requirements. Contemporary manufacturing processes and emerging technologies have been developed to meet these challenges [2] and [3].

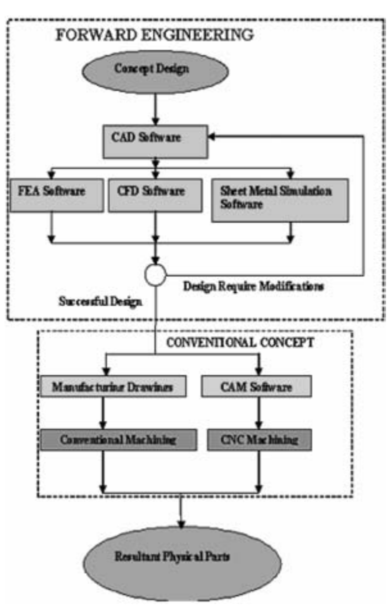


**Fig. 1.** Basic approaches in forward engineering

CNC machining is an up coming engineering field in contemporary manufacturing in Pakistan. CNC machining in the digital environment adds a new facet in gaining competitive advantage to meet the present day industrial challenges.

The dynamic requirements of customers urges the manufacturing specialist to design, develop and manufacture components in the least possible time with maximum features, functions, flexibility to change and easily.

In response to these challenges, the manufacturing specialist changed the component's design and development processes from series to parallel and then concurrent so as to meet these challenges. Digital manufacturing (CNC Technologies) provides a solution to the challenges. Figure 1 shows the approach of CNC manufacturing in Forward Engineering.

## Important terms

Some important terms relating CNC machines are as under:

## CL Data

Cutter Location Data (CL data) files are generated from the cutter paths specified within NC Sequences. Each NC sequence generates a separate CL file. These CL data files can then be passed to machine-specific or generic post-processors for NC tape generation, communications or MCD generation as follows [4].

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FORMAT/MM
LOADTL/1, OSETNO, 1
CAMERA/1,0,0,0,0,1,0,0,0,0,1,0
SPINDL/RPM, 2700, CLW

### Machine control data (MCD)

These are the set of instructions that are directly interpretable by the CNC processors. MCD generated depends on the Post Processor (PP) used. It is produced in punch file (.Pui). These can be interpreted only by expert. Each alphabet and integer has a specific meaning in the MCD file as follows [4].

N10 G0 G17 G99
N15 G0 G17 G99
N20 G90 G94

### Processor panel

Every industrial CNC machine has an electronic panel, industrially known as 'Processor Panel'. The 'Processor Panel' gets it name from one of component which is a processor. This processor component is the same as used in a Personal Computer (PC). This 'Processor Panel' has many other components such as the display screen, typing pad, emergency stop switch and some other auxiliaries.

### Control software

The control software translates the MCD into relevant pulses to control the motors mounted on the milling machine. These pulses are transferred to the motors by serial or parallel port of a PC.

### NC sequence

Material removal is an assembly feature that can be created to represent the material removed from the work piece by an individual NC sequence

## Converting manual milling machine to CNC milling machine

Figure 2 shows the working of an industrial CNC milling machine. Whenever manual milling machines are converted to CNC it is required to import the 'Processor Panel'. Now, all that is needed is a PC to carry out CAD and CAM and the rest is left to the 'Processor Panel'. The problem is that imported 'Processor Panels' are very expensive. So an attempt has been made in this research to avoid import of such expensive 'Processor Panel' by using a normal PC.

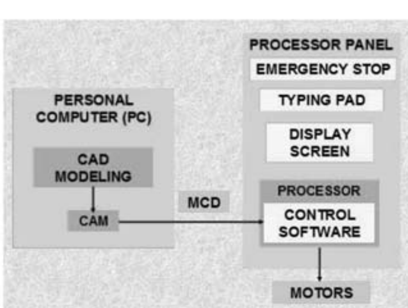



**Fig. 2.** Working of an industrial CNC milling machine

### Proposed concept

An attempt has been made to use the PC's processor instead of an imported 'Processor Panels'. The idea is to install the control software on a PC and interpret the MCD in such a manner that the relevant pulses are produced on the parallel port. These pulses can then be directly supplied to the motors mounted on the milling machine structure, thus avoiding the need of an external processor panel. Figure 3 shows the proposed concept of CNC milling machine.

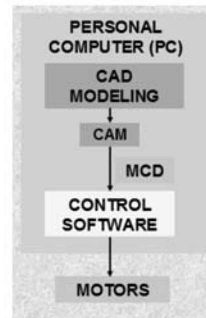



**Fig. 3.** Proposed concept of a CNC milling machine

### Brief description of the designed CNC milling machine

Figure 4 shows the main features of the CNC milling machine. All three axes of the milling machine are translational. Each axis has a lead screw and two supporting rods. The lead screws are rotated by the motors installed at the ends to create translational motion. These supporting rods guide the linear motion. The base of the demonstration model CNC Milling machine is 420mm x 420mm, height is 450 mm and its chuck can hold a cutter up to 3mm diameter.

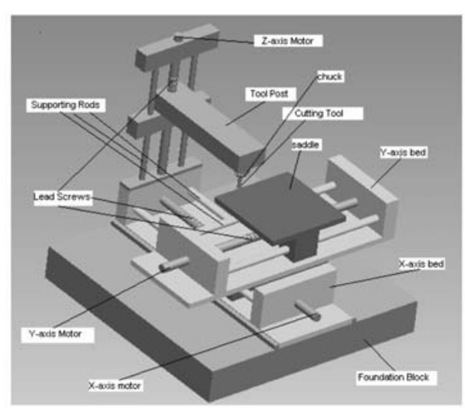



**Fig. 4.** Components of the CNC milling machine

## Project design approach

The following actions were taken in the design process.

- 3-D Solid Modeling in Pro/Engineer.
- CL DATA generation in Pro/Engineer for the 3-D Solid Models.
- Post Processing of CL DATA into MCD.
- Reading of MCD by TurboCNC to produce corresponding electronic pulses on Parallel Port.

- Reception of the pulses on to a Microcontroller.
- Processing of these pulses by the micro controller to control the stepper motors.
- Design of the stepper motor drives.
- Synchronization of the whole process to carry out experimentation.

The project design approach is shown by a Flow Diagram in Figure 5.

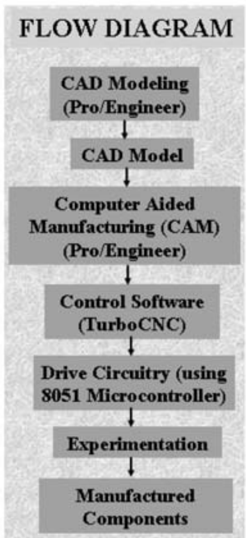



**Fig. 5.** Project design approach

## CAD modelling

CAD modeling is carried out in the CAD software Pro/Engineer. The following two models have been created keeping in view the intent of elaborating all the features of a 3-axes milling machine [5], [6], [7]. Moreover, these models do not contain any such features which are not possible to be machined by a 3-Axes CNC Milling machine as shown in model 1 and 2.

**Fig. 6.** Front view of the model no. 1


**Fig. 7.** Front view of the model no. 2

## Drawings

The following figures show the drawings for Models 1 and 2.

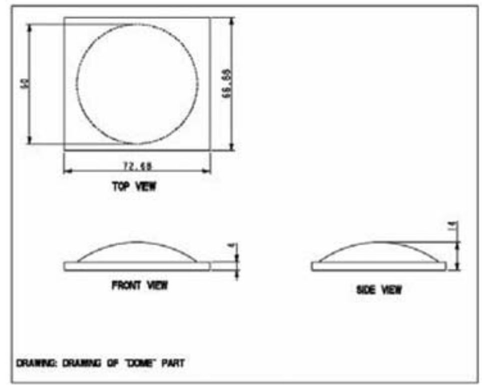



**Fig. 8.** Drawing of model no. 1

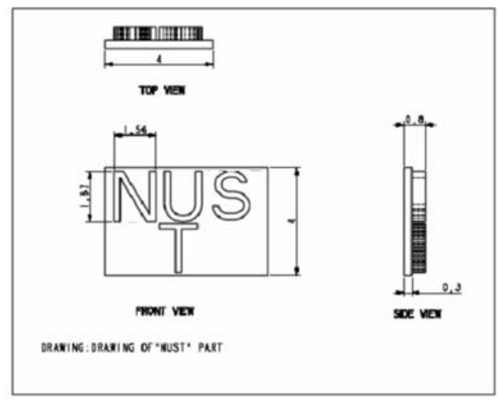



**Fig. 9.** Drawing of model no. 2

## CAM

These models then undergo CAM. CAM has also carried out in Pro/Engineer. Through CAM the MCD file is generated. The process of CAD and CAM is carried out using a PC. During CAM, first the Cutter Location DATA (CL DATA) is created and then it is Post Processed into Machine Control DATA (MCD). Figure 10 shows the flow diagram of CAM [8], [4].

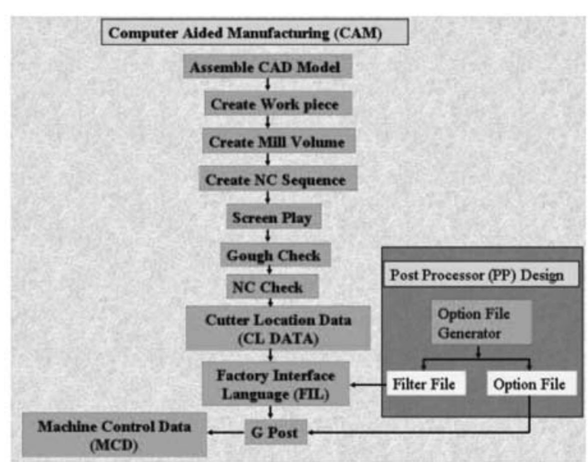



**Fig. 10.** Flow diagram of CAM

In this paper the CAM for only Model no. 1 has been defined.

### Defining work piece

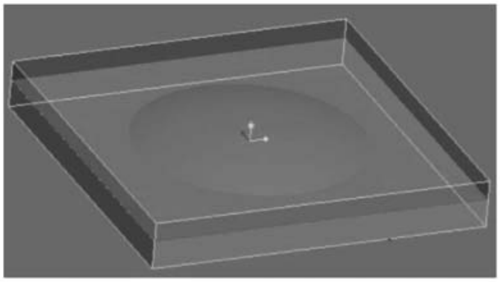


**Fig. 11.** Model along with work piece

CAM requires the definition of the work piece geometry from which the model is to be milled out. Figure 11 shows the work piece (in green colour) over the model.

### Defining milling volume

It is basically the space allowed for the cutter to move in. It is created in the same way in which work piece is created. It appears in the gray colour over the work piece as shown in Figure 12 [4].

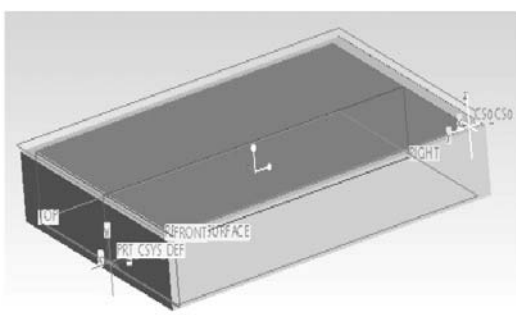



**Fig. 12.** Model with milling volume

### NC sequence

The NC Sequence can be defined from the main menu **Machining> NC Sequence**. Upon entering the sequence name and conforming ☑ the **tools setup** menu as shown in the Figure 13. The cutters name, diameter and its length, volume to be machined are necessary to be defined [4].

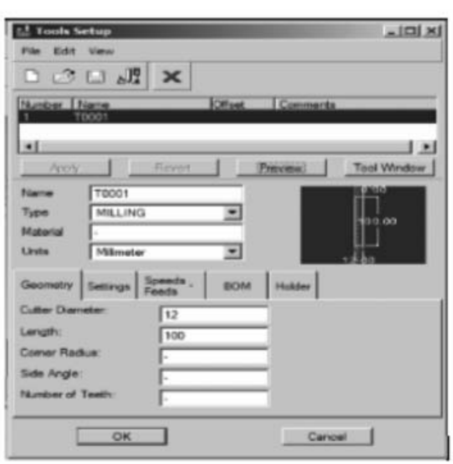



**Fig. 13.** Tool setup menu bar

### Defining manufacturing parameters

Manufacturing parameters are defined from **MFG PARAMS > SET** to set the parameters. This includes parameters such as cut feed, step depth and cut angle etc. Figure 14 shows the manufacturing parameters menu.

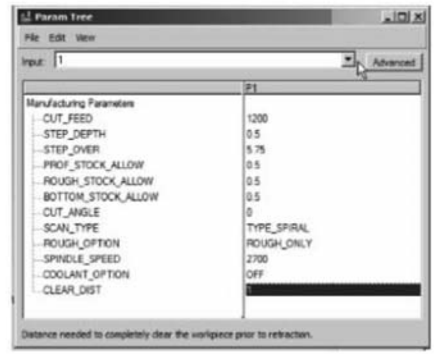
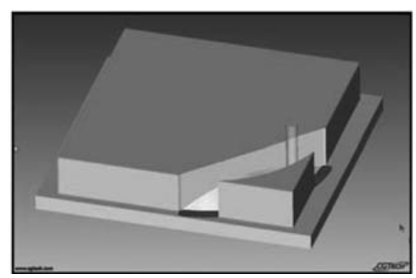


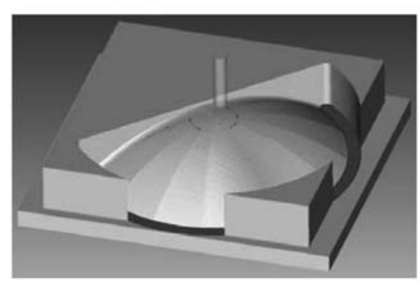

**Fig. 14.** Manufacturing parameters of machining

## NC check

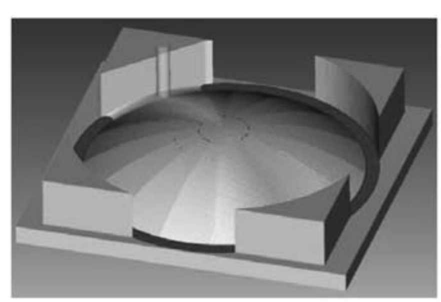
NC Check is carried out in VERICUT software. The NC Check simulates the cutter positions and material removal as shown in Figure 15 [4].



**Stage no. 1**



**Stage no. 2**



**Stage no. 3**

**Fig. 15.** Different Stages of Machining in VERICUT Environment for NC Check

### Generating machine control data

For the purpose of NC CHECK, GOUGE check and screen play Pro/Engineer uses CL DATA. After verification by these checks, the Cutter Location DATA (CL DATA) is converted to machine control data (MCD) by Post Processing [8], [4].

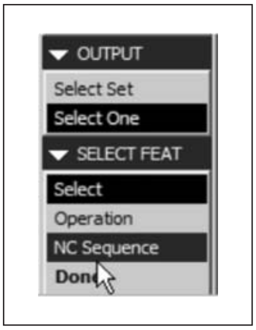



**Fig. 16.** Post Processing of NC Sequence

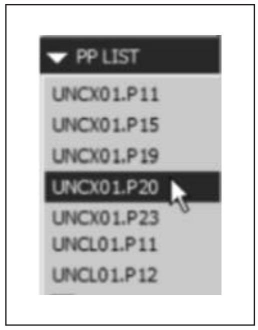



**Fig. 17.** PP List Menu Bar

The NC SEQUENCE to be Post Processed and the type of PP to be used can be selected from the main menu options **MACHINING > CL DATA** as shown in Figure 16 and Figure 17.

### LOG file

Before generation of MCD information window of the LOG FILE is displayed, which shows the statistics of the NC Sequence, to confirm all inputs. The file also shows tape length, cycle time and any warnings etc [4]. The LOG File is shown in Figure 18.

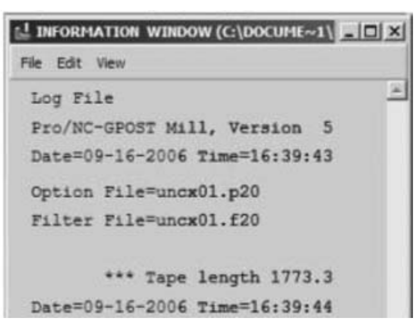



**Fig. 18.** LOG file

### MCD file

Upon confirming the inputs as stated in the LOG file, the MCD FILE is generated as shown in the Figure 19.

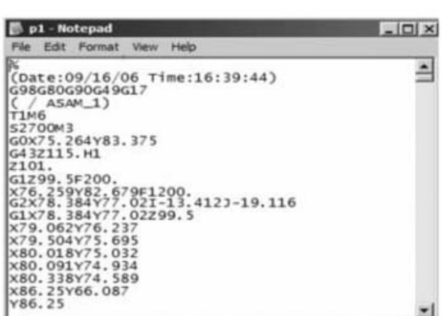



**Fig. 19.** MCD file

### NC post-processing

Pro/NC generates Cutter Location (CL) data files in an ASCII format that need to be Post Processed to create MCD files before any machining operation occurs. CNC machines work on a specific standard of MCD, also known as G-Codes. The problem lies in the fact that there are many standards of MCD and it is required to translate CL Data to the standard that the control software can understand. In this research work, the control software (TurboCNC) used can only understand the standard RS-274D [9]. So, it is required to translate CL Data to RS-274D standard. Some defaults Post Processors (PP) are available in Pro/NC but none of them is based on RS-274D standard. So, it is needed to design a new Post Processor.

### Layout of post processing process

Figure 20 shows the generation of MCD punch file (.PU1) from CL Data using Generalized Postprocessor (GPost) [4].

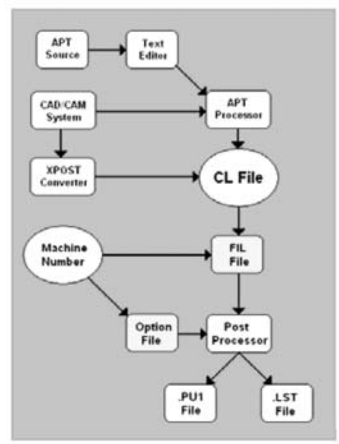



**Fig. 20.** CAD/CAM – GPOST system flow chart

The Post Processor reads the CL File as input. In addition, it reads machine information from an option file created by the user using the Option File Generator. The postprocessor converts the input CL into a MCD punch file (PU1).

### Post processor design

There are two steps or ways to design a Post Processor for a particular machine [4].

### Option file

OPTFILE.EXE is the Option File Generator that enables designers to set machine control parameters. The postprocessor reads the option file to override the default values to generate customized output.

### FIL file

The Factory Interface Language (FIL) is used to customize the postprocessor output. FIL is a text based MACRO language. Using OPTFILE.EXE, the FIL file is automatically created with the Option file. The Post Processor reads the FIL file after reading the option file.

## Method of initializing a PP

All postprocessors are initialized from existing PP beacuse changes are easy to make as compared to designing a PP from scratch. Selection of the FANUC Post Processor was made in this research [4]. The reason for choosing Fanuc Post Processor was that, it was a 3-axes milling machine with the default G-Codes similar to the RS-274D standard.

## The option file generator

In this research project, only the option file is generated. For creating and editing an option file, the option file generator is launched. After launching the 'Option File Generator', the main menu will appear shown in Figure 21 [4].

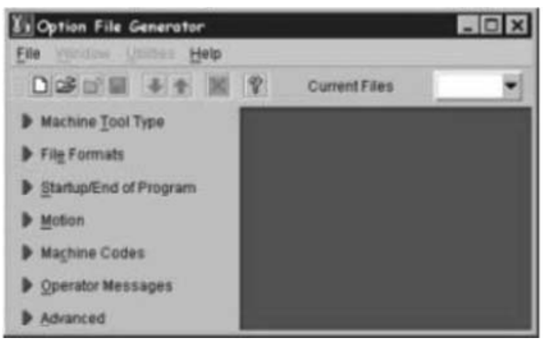



**Fig. 21.** The option file generator main menu

## Customizing the option file

Once the 'Option File Generator Main Menu' appears, it is ready to start customizing the option file as shown in the Figure 22

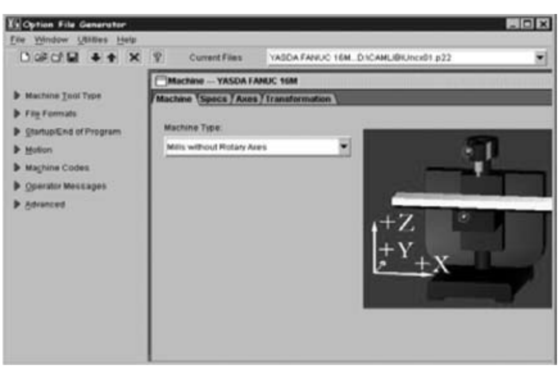



**Fig. 22.** Customizing the option file

The option file generator consists of several menus and options which needs to be defined. The FIL File can also be accessed from the option file generator.

## Control software

Turbo CNC (TCNC) is a machine control interpreter which works on the standard RS-274D. After a MCD program is executed, each line is picked by the TCNC and executed. Execution of the TCNC commands results in the production of pulses on the parallel port, the pin on which the output is desired and its format can be adjusted.

The main menu of TCNC is shown in Figure 23 [9].


**Fig. 23.** TCNC initial diagnostic screen

## Jog machine

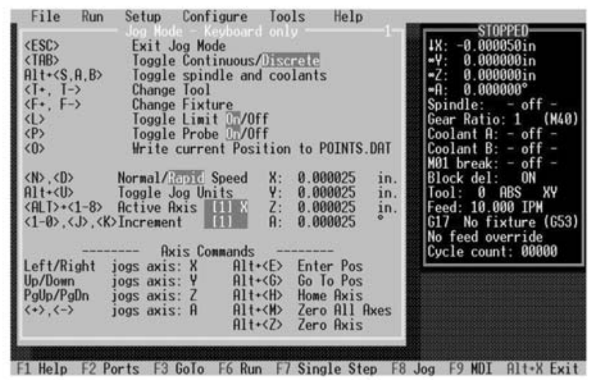



**Fig. 24.** TCNC jog mode

This option is available at SETUP > JOG MACHINE. In Jog Mode, keys are assigned functions that move axes. This mode is used to set the tools to the program zero of the work piece in preparation for cutting. The JOG MACHINE menu is shown in Figure 24 [9].

## Configuring the axes

The 'Configure' option is used to configure the parallel port I/O to drive the system, set tool and fixture offsets, and maintain the configuration file (turbocnc.ini). This option is available on the main menu as shown in Figure 25.

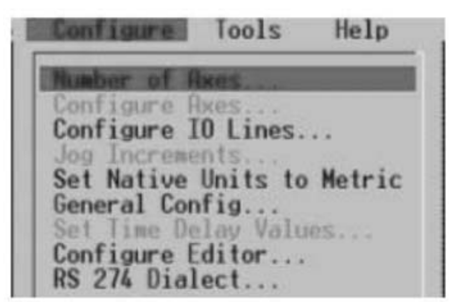



**Fig. 25.** TCNC configuration menu

## Port monitor

The TCNC Port Monitor can be used to help troubleshoot problems in the interfacing. The default settings, and display IS shown in Figure 26.


**Fig. 26.** TCNC port monitor

### 8051 Microcontroller

Intel's 8051 based microcontroller was used in this research experimentation for its cheapness, ease of availability and easy of programming [10], [11].

### 8051 Assembly programming

Assembly programming was used in this project to control the microcontroller.

### Assembling and running an 8051 program

Assembly programming was used in this project to control the microcontroller. The steps to create an executable 'Assembly Language Program' are outlined as follows [10], [11].

- First, MS-DOS EDIT editor was used to type in the assembly program.
- The "asm" source file containing the program code created in step 1 was fed to an 8051 assembler. The assembler converted the instructions into machine code i-e object file "obj" and a list file "lst".
- Then, the program is linked. The link program takes one or more object files and produces an absolute object file with the extension "abs".
- The "abs" file was then fed into a program called "OH" (object to hex converter) which creates a file with extension "hex" that is ready to burn into ROM.

### Stepper motors

In this project unipolar stepper motors were used for the tool and bed motion of the CNC milling machine.

Each stepper motor has 5 wires coming out of it. Four of those wires are each connected to one end of one coil. The extra wire is called 'common'. The 'common' wire is connected to the supply voltage, and the other four coil wires are connected to ground through transistors.

The microcontroller is then used to activate the transistors in the right order.

### Drive circuit, the darlington transistor

In this research, electric circuitry was designed using Darlington pair. The Darlington pair used in this project is made of discrete transistors i.e. D313 and C945. It has a combined β of 50,000 (250*200) and can deliver a maximum current of 3A.

### Generic board

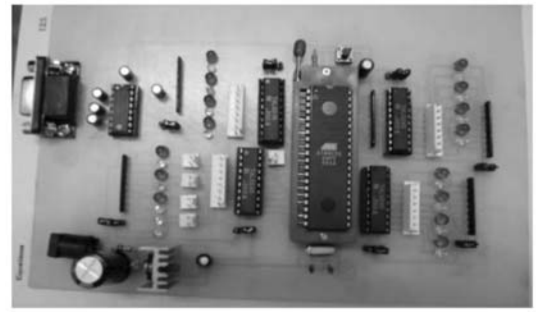


**Plate 1.** Generic board

A Generic Board is a general purpose trainer board for the microcontroller which is used to test working of almost any program written for the microcontroller. A generic board was developed to understand and test the fundamental concepts of microcontroller and electric circuits. Plate 1 shows the generic board developed for this research work.

### Schematic of the final circuit

Schematic for the final hardware circuit is shown in Figure 27.

It contains an on-board voltage down-converter and regulating circuit. For each motor a separate microcontroller was used and each coil of a motor is driven by a separate Darlington pair. Hence, on each motor's circuit there were four Darlington pairs.

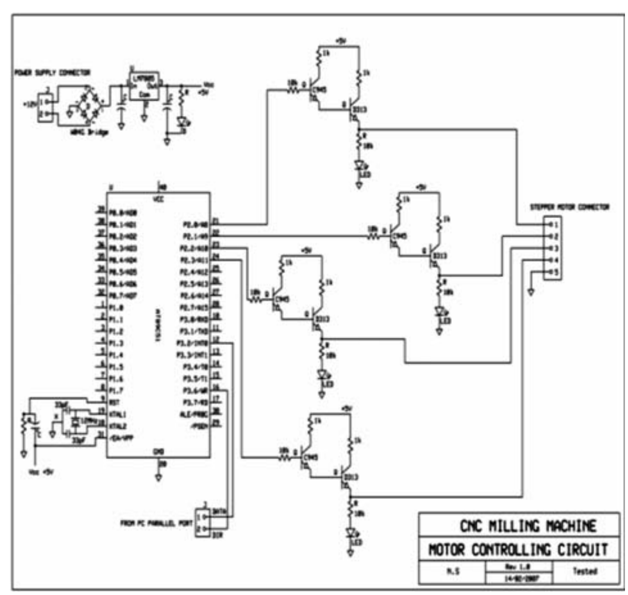



**Fig. 27.** Schematic of the final circuit

## Experimentation

Experimentation was carried out to verify all the design parameters. The experimentation started by manufacturing basic shapes, such as lines and circles. Different problems were encountered during this step. Elimination of errors in the basic shapes is a pre-requisite for manufacturing complex 3-D components.

### Basic shapes and problems

Basic shapes, such as lines along each axis, lines in a plane and circle, are tested before manufacturing a 3-D model from the MCD generated by Pro/Engineer

### Lines along x and y axes

The milling machined worked smoothly in X and Y axes separately. But there was a problem of size. The length of the actual cut was always larger than that desired. A linear cut of 10 mm resulted in a linear cut of about 14 mm

### Line in x and y axes simultaneously at different angles

The milling machined worked smoothly in X and Y axes simultaneously. However, the motion of the cutter was always at an angle of 45$^o$. No matter what value was entered to x and y axes the result was a line at 45$^o$ with the length of the longer side at both the axes as shown in Plate 2.

### Circular shape

The circle drawn was a complete chaos. The semicircular cut was manufactured as a combination of three lines as shown in Plate 3.

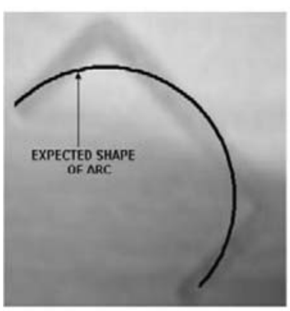



**Plate 3.** Wrong circular shape

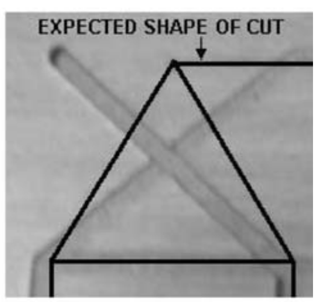



**Plate 2.** Wrong slanted lines

### Model House

In order to better visualize these problems, an attempt was made to engrave a model house. The result of executing this program was also not much encouraging as shown in plate. All the above mentioned problems were visible in this part.

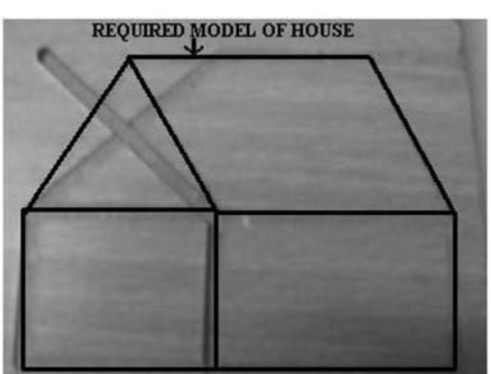



**Plate 4.** Incorrect house

## Solution

### Step size of the motors

The step size of the motors was rated incorrectly on the motors. This was causing the problem of size. The motors were rated as 1.8$^o$ step size which was in fact 2 $^o$. Necessary adjustments was made in the control software.

### Pulse width

The axes were configured to give pulses at parallel port of pulse width 10 milli seconds. It was later on found that the motor required 100 milliseconds to complete one complete step. This configuration resulted in missing and mixing of pulses.

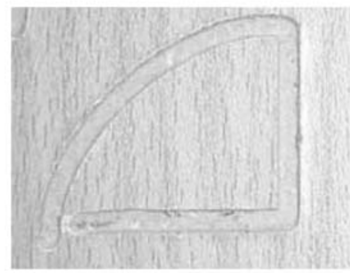


**Plate 5.** The quarter circular cut

Due to this problem the x y simultaneous motion was only at 45$^o$. After correction, the lines can be manufactured at all desired angles. ]This also corrected the problem of circular motion as shown in plate 5.

### Test models


**Plate 6.** Work piece of model no. 1

After successful experimentation of basic shapes, complex parts were also manufactured. Although, due to the non-rigid behavior of the mechanical structure, the accuracy of the components was not outstanding, the machine successfully verified the design, tool paths, cut depths and all other design parameters. Plate 6 and 7 shows the work piece of model #1 and model # 2.

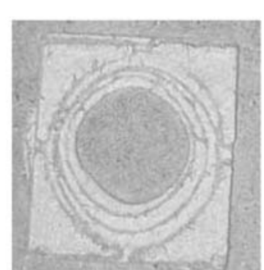


**Plate 7.** Work piece of model no.2

## Discussion and results

The indigenous design of the demonstration model 3-Axes CNC milling machine was successfully conceived and developed. The following goals were achieved successfully;

- The CNC milling machine interfaced with Pro/Engineer was designed.
- It successfully works as 3-Axes milling machine
- Although, the accuracy of the CNC milling machine is limited, it successfully verified the design and concept.

## Conclusion

The conclusions drawn from the experimentation work of this project are presented as follows:

- CNC's are one of the best approaches for developing complex entities, attaining excellent quality, less scrape and rejection, low cost and reduced time.
- Latest technologies and CAD and CAM softwares enable to design, visualize and validate complex entities product in virtual environment prior to their manufacturing.
- 3-D CAD and CAM softwares enable higher flexibilities.

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