An Investigation of CNC Thermal Cutting Machine Development and Evaluation

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Abstract

This article aims to develop and evaluate a Computerized Numerical Control (CNC) motion system for a thermal cutting machine. A PC-based numerical control unit was constructed and other system software and hardware requirements e.g. position measurement system and data I/O interface units were proposed and developed. The approach was set to replace as much as possible the specialized CNC hardware components by specially developed software that could achieve their function equivalently, thus leading to simplify the hardware construction of such machines.

A set of automatic data processing algorithms was proposed and developed to accommodate the requirements of this study. Algorithms for path generation and two axes interpolation were applied and assessed. Algorithms for motion path control were accomplished and tested.

Implementation of the proposed system has been successfully applied and contour shapes were cut. Results also assured that the proposed system could establish an adequate base of CNC machines construction for automated thermal cutting process, which meets the industrial implementation requirements.

البحث في تطوير وتقييم مكائن القطع الحراري المبرمجة بواسطة الحاسوب

الخلاصة

تهدف المقالة الى ايجاد وتطوير نظام مبرمج للسيطرة على الحركة لمكائن القطع الحراري المبرمجة بواسطة الحاسوب. تم بناء وتطوير وحدة للسيطرة الرقمية المعتمدة على الحاسوب الشخصي بالاضافة الى متطلبات النظام الاخرى من المكونات المادية والبرامج الحاسوبية مثل نظام حساب الموقع ووحدة المدخلات والمخرجات. النظام المقترح تم بناءه بحيث يضمن –الى حد كبير– أستبدال أجزاء المكونات المادية للماكنة بمكونات مرنة متخصصة تقوم بتنفيذ كل مهام المكونات المادية وهذا بدورة يؤدي تسهيل متطلبات بناء المكونات المادية لهذه المكائن. تم أقتراح وتطوير مجموعة خوارزميات لمعالجة البيانات لانجاز متطلبات البحث. تم تقييم وتطبيقات خوارزميات لتوليد مسار العدة وخوارزميات للأستكمال ثنائي الابعاد. وكذلك تم بناء وتقييم خوارزميات للسيطرة على حركة العدة. النظام المقترح تم تطبيقة بنجاح على مجموعة من الاشكال المختلفة. أكدت النتائج أمكانية أعتماد النظام المقترح كأساس لأتمتة عمليات القطع الحراري للمكائن المبرمجة والتي تلبي المتطلبات الصناعية.

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1. Introduction

Thermal cutting processes differ from mechanical cutting (machining) in that the cutting action is initiated by chemical reaction (oxidation) or by melting (heat generated by the arc) [1].

A number of thermal cutting processes were developed to sever, gouge or remove metals from plates or other raw material types so as to produce smaller pieces or prepare edges for joining by application of welding. These processes are also found in foundry to cut protrusions like runners, risers, gates, ... etc., or for cutting scrap to manage lot size for transportation or disposal. Some of thermal cutting processes have been widely used in industrial applications such as Oxy-fuel gas cutting, Plasma arc cutting, and Laser beam cutting [2], however, using these processes to cut contour shapes require complete identification of tool movement path.

Although manual controlling of tool movement to generate and cut required contoured paths are used frequently in many industrial applications, this method is not always favorable due to the limited accuracy of achieved cut contours. In addition, manual cutting process requires firm, steady and continuous holding of the handheld cutting tools, thus making the job inconvenient and may present a hazardous working condition. Hence using controlled path machinery in thermal cutting applications would present a beneficial alternative.

The use of automated equipment and CNC systems could be considered currentlyas one of the most important elements of automated manufacturing systems [3]. By utilizing modern computer methods, configuration tools can be provided and used to select and aggregate control system modules, this would result in the generation of machine controllers with much reduced systems engineering costs but high levels of functionality which can be readily extended and supported [4].

Stanton [5] stated that the roots of the numerical control go back to the 17th century when punched cards were used in woven patterns, and in the 18th century in player pianos.

The U.S. Air force adopted a research aimed to develop NC milling machine together with the Parsons Corporation in Michigan in the late 1940s. A prototype NC milling machine was demonstrated by MIT in 1952 [6].

An important advance in the philosophy of NC machine tools, which took place during the early 1970s, was the shift towards the use of computers instead of controller units in NC systems. This produced both the computerized numerical'control CNC and the direct/distributed numerical control DNC machine tools [7], hence opened the way to the continuous improvements in this side of technology.

2. Proposed CNC Motion System Hardware

An IBM compatible PC/XT was used in the developed system to establish required contrnl function. ESAB RPC 320 plasma power supply unit with plasma torch type PM 600 was accommodated in the systzm .In addition an ESAB injector Oxy-Fuil cutting (OFC) equipment was adopted and used, however, the developed system could facihtate the use of other types of Plasma .Arc Cutting (PAC) and OFC equipment.

The mechanical structure of the developed system is based on a gantry type structure; hence, no special floor foundation is required for machine installation. The driving mechanism used for both axes is based on the rack and pinion mechanism.

Two indMduals D.C servomotors are used to obtain the required movement. A third motor is also used to adjust the height of the torch.

Special carriage and fixture were designed and manufactured by the authors to enable the setting of measurhlg system equipment on the structure. A supporting table is provided with the machine to carry the sheet metal. Figures (1.a, 1.b and 1.c) show photographs of the developed machine and its major components, where as Figure (1.d) shows a block diagram of the developed system hardware.

The longitudinal travel limit of the machine (y-axis) is 2800 mm and the traverse travel (x-axis) is 2800 mm. The transmission power was designed to enable both PAC and OFC processes. The allowable range of the D.C motor rotational speed is between zero revolutions per minute and maximum 6000 revolutions per minute in both directions. The two driving units of the machine are individually coupled tO the slide positioning mechanism of the machine axes.

The front end of the motor shaft is coupled to a gear mechanism to enable power transmission to the machine-sliding axis using a specially designed gear. Fine pitch gear teeth was selected to achieve better performance and reliability [8].

The gear module (m) was selected to be 1.25 and gear number of teeth is 25 teeth, therefore, the pitch diameter of the gear used is equal to (31.25). The perimeter of the pitch diameter circle (pe) is equal to 98.2 mm which indicates that one pinion revolution gives a 98.2 mm. linear displacement of the moving machine axis slide.

The maximum rotational speed of the D.C. motors used is 6000 rpm, however, this x, alue is reduced by the 120:1 reduction gearbox, therefore; the maximum output rotational speed is 50 rpm. Thus, 'the maximum linear feed rate, which could be obtained from the developed system, is 4910 mm/min (apProximately 80 mm/sec.).

2.1 Position Measurina System

Position measuring system is usually implemented in CNC machines to enable acquiring coordinate positioning information and feeding it back to the system to achieve closed loop control. In the developed system an incremental rotary encoder [7,9] was used as a measuring system feedback sensor. The resolution of the encoder used is 1500 pulse/rev. Two encoders were used in the system, one for each axis. Encoder mounting and engaging parts were designed and manufactured by the authors to achieve accurate fitting with the slide mechanism of the machine. A great deal of care was taken while component was assembled to assure good protection against breakage. A standard universal joint was used to join the pinion to the shaft encoder via specially manufactured Teflon joint, which is desirable to keep inertia and noise at minimum [8]. This universal joint is capable of motion transmitting up to 24° inclination. In addition selected ball bearings with specially manufactured brackets were used to achieve the complete mechanism.

The position measuring unit was set up on the machine structure and full alignment relative to tile rack was achieved for both x and y axes.

The resolution of CNC systeins depends mainly' on the feedback signal obtained from tile position measuring unit [7]. Tile higher the pulses generated and processed by the measuring system, due to a specified linear movement of the machine slide, the higher the resolution achieved.

In the developed system the same rack, used for tile slide driving was used to generate the rotation action of the shaft encoder via a specially designed and manufactured pinion. The pinion module (m) was selected to be 1.25 to match the rack module. Theoretically it is preferable to obtain an integer number of encoder pulses relatively generated due to a unit length linear movement (e.g. 1 mm), to overcome inhibited errors, hence, a 38 teeth pinion is selected, thus the perimeter ofjts circle pitch (pe) Is equal to 149.285 mm.

The inhibited error would then become equal to 0.04 pulse per 1 mm, (i.e. 0.004 mm per unit length of 1 mm), which is equivalent to 0.004 pulse per sample if 10 Samples per mm are taken. Each encoder pulse is approximately equivalent to 0.1 mm.

2.2 I/O Interfacing Unit

An input-output (I/O) interfacing unit was specially built for this work to link the hardware system to the developed software system. This unit consists of two electronic circuit boards, the first is used to control the motor drivers (i.e. motor control board), and the second is used for controlling the measuring system. Figure (2) shows the I/O interfacing units.

The two built cards were designed to achieve 2 axes controlled motion. They were set to use the standard PC Ido bus [10]. The I/O ports are addressed by the developed software to allow data transfer.

2.3 Motor Driver Interface Board

The main function of this board is to convert the digital information produced by the software on the computer to a proportional analogue voltage to feed the D.C. servomotor driver board. This is accomplished by using digital to analogue converter DAC and special ICs components [7,11].

The card was designed to control two channels in order to feed two motion axes. Each channel carries the voltage signal to actuate one axis driving motion unit. Two 12 bit DAC's and one PPI (Programmable Peripheral Interface) IC were used in addition to relays and other electronic components for signal filtering and modification. Other I/O channels were also provided in the card for future expansion. The signal output from the 12 bit DAC is equivalent to 4096 stages of resolution, yielding 2048 +ve and 2048 -ve speed ranges. The DAC type used is DAC 80-Burr Brown [12], and the PPI type used is PPI 8255 [13]. Figure (3.a) shows a simple schematic diagram of the built card.

2.4 Position Measuring System Interface Board

The developed board receives the signals emitted by the encoder, which are represented as pulses. The encoder emits two signals, the first signal represents the incremented movement to indicate relative resulting rotational movement, and the second signal provides the movement direction, I which is +ve, or -ve direction.

The card has four channels for input because two channels are required for each encoder axis. The built board uses a hardware counter component type 8253 triple down 16 bit counter [13], this component consists of three single counters each of 16 bit (two ofeightbit registers). A status register IC is used to give the movement direction indication. Other electronic components are also used to receive the emitted encoder signals such as line receiver 75175 type ICs [13].

Only two counters of the triple counter chip are used while the third is reserved for future expansion (e.g. actuating a third axis of motion). Figure (3.b) presents a simple schematic diagram for the built card.

3. Hardware Functional Test

The machine structure used was successfully tested according to DIN 8523 specification. The , developed gantry type structure is easy to manufacture and install, in addition, it is suitable for torque less cutting operations like thermal cutting processes.

A physical interface of the developed system hardware was achieved with the PC via I/O PC bus and operated successful. In the early stages, the driving unit was operated alone. Voltage was supplied with various ranges and hence various speed ranges were obtained. Each axis was tested separately, and then two axes were tested simultaneously. Smooth motion was noticed and good motor braking response was obtained.

The measuring unit was then operated alone. Good response was obtained for uni-axis motion and for two axes simultaneous movement.

Both the driving and measuring units were together operated and tested (uni- axis movement and two axes simultaneous movements). In both cases good response were obtained.

4. Controller Procedures

The developed controller is basically an on-line PC, programmed to achieve both control and supervisory functions. Figure (4) shows the block diagram of the developed controller software. The main functions and procedures of the developed controller software are as follows:

4.1 Program Editor and Setting Procedures

Figure (5) shows the adapted part program structure. The part program consists blocks of words; each word contains an address followed by specific values that present an activity. The developed procedure allows editing 9999 blocks. The user supplies the computer with the required information interactivity. A re-storing procedure is included in the developed software to allow the re-arranging of the entered block data according to their accurance. The used preparatory functions are:

Gl: Linear interpolation.

G2: Circular C.W. interpolation.

G3: Circular C.C.W interpolation.

After finalizing program edit, the user is required to set the values of the Work-piece Reference Point (W.R.P), which is presented by two axes coordinates (X&Y) relative to the Machine Reference Point (M.R.P).

The machine reference point (M.R.P) has no operating effect, but all generated cutting paths of the shapes are to be calculated relative to its position. Figure (6) shows the machine coordinate system used.

The developed software procedures enable the displaying and editing of previously prepared and stored part programs to allow checking and updating. Figure (7) shows a block diagram of the included procedures.

4.2 Path Generation Procedures

Although many systems use path information generated by CAD packages like AutoCAD [14, 15], the developed system generates path information using user defined data that may be entered manually or re-called from previously prepared data files. The software allows the creation of any contour shape that may be composed of lines and arcs. Following is a brief discussion of the developed procedures.

4.2.1 Loading/Parsing Procedure

This procedure prepares the required information for the later vectorization program (section 4.2.2). Data information is loaded sequentially to the working memory from a previously prepared path information file. Suitable information algorithms are selected and executed automatically to match required geometrical data. Figure (8) shows a flow chart of the loading / parsing procedure.

4.2.2 Interpolation and Vectorization Program

Most of CNC systems use special hardware components known as interpolators [7] to achieve tile interpolation function, however, non-of these components is used in the developed system. Instead, the interpolation is achieved using specially developed software procedures, and hence the system interpolator used is a software program.

This developed program classifies the interpolation functions into two types, namely linear interpolation and circular interpolation, where the latter is divided into C.W. circular interpolation and C.C.W. circular interpolation.

The program serves to give two functions namely:

1- **Interpolation:** At which each two points in the sequence are linked (interpolated) by segments (or vectors). Segment positions are determined to fit the required contour pattern. When the segment is composed of a straight line, the interpolation is set to linear approach, and when it is composed of arc then the interpolation is set to circular approach.

2- **Vectorization:** (or discretization): The determined interpolated path is to be discretized into equal length vector units. Vector length unit affects tile smooth ability of the generated path. Smaller vector length would give smoother path and vice versa, however, an important factor must be taken in account when choosing the .vector length unit which is the response time for both the sending out signals and the on-line calculations in order to maintain the continuity of the resulting path.

The program results in a data file containing the generated-discretized path coordinates.

a. Linear Interpolation

The following assumptions are suggested and employed for the movement cases to compute the linear vector angles relative to the required motion directions. Figure (9) shows these assumptions. The conditions of the suggested assumptions are:

Case 1: $x_1 < x_2$ and $y_1 > y_2 \rightarrow$

$$\theta = \tan^{-1}\left(\frac{\Delta y}{\Delta x}\right)$$

Case 2: $x_1 > x_2$ and $y_1 > y_2 \rightarrow$

$$\theta = 180^{0} + \tan^{-1}\left(\frac{\Delta y}{\Delta x}\right)$$

Case 3: $x_1 > x_2$ and $y_1 < y_2 \rightarrow$

$$\theta = 180^{0} + \tan^{-1}\left(\frac{\Delta y}{\Delta x}\right)$$

Case 4: $x_1 < x_2$ and $y_1 < y_2 \rightarrow$

$$\theta = \tan^{-1}\left(\frac{\Delta y}{\Delta x}\right)$$

Case 5: $x_1 < x_2$ and $y_1 = y_2 \rightarrow \theta$ = zero

Case 6: $x_1 > x_2$ and $y_1 = y_1 \rightarrow \theta = 180°$

Case 7: $x_1 = x_2$ and $y_1 > y_2 \rightarrow \theta = 270°$

Case 8: $x_1 = x_2$ and $y_1 < y_2 \rightarrow \theta = 90°$

Figure (10) shows the flow chart of the linear interpolation and vectorization algorithm

b. Circular Interpolation

This type of interpolation is classified as clockwise (C.W) and Counter Clockwise (C CW), circular interpolation. Each type has special conditions and cases. The following two sections explain the suggested assumptions used in the development of the (CW. and C CW) interpolation algorithms.

1- C.C.W Circular Interpolation:

The algorithm of this interpolation and discretization routine is shown in Figure (11) The C CW interpolation function is usually obtained by applying the preparatory function of G3 For each circular path to be shaped with (CCW) direction, a start point(s) with start angle (A) and end point (E) with end angle (B) must be given. In addition, the coordinates of the center point of the circular path (point C) must also be defined the angle restricted between both the start angle and end angle is 0 which must be positive (i.e. B>A).

The suggested and employed cases and assumptions for this (C.C.W) interpolation are tile followings:

- **Case 1:**

$$x_s > x_c \text{ And } y_s > y_c \rightarrow A = \tan^{-1}\left(\frac{y_s}{x_s}\right)$$

$$x_e < x_c \text{ And } y_e > y_c \rightarrow B = 180 + \tan^{-1}\left(\frac{y_e}{x_e}\right)$$

- **Case 2:**

$$x_s < x_c \text{ And } y_s > y_c \rightarrow A = 180 + \tan^{-1}\left(\frac{y_s}{x_s}\right)$$

$$x_e < x_c \text{ And } y_e < y_c \rightarrow B = 180 + \tan^{-1}\left(\frac{y_e}{x_e}\right)$$

- **Case 3:**

$$x_s < x_c \text{ And } y_s < y_c \rightarrow A = 180 + \tan^{-1}\left(\frac{y_s}{x_s}\right)$$

$$x_e > x_c \text{ And } y_e < y_c \rightarrow B = 360 + \tan^{-1}\left(\frac{y_e}{x_e}\right)$$

- **Case 4:**

$$x_s > x_c \text{ And } y_s < y_c \rightarrow A = 360 + \tan^{-1}\left(\frac{y_s}{x_s}\right)$$

$$x_e > x_c \text{ And } y_e > y_c \rightarrow B = \tan^{-1}\left(\frac{y_e}{x_e}\right) \text{ if } B > A$$

$$\text{or } B = 360 + \tan^{-1}\left(\frac{y_e}{x_e}\right) \text{ if } B < A$$

For all cases, if B < A then B is set to B +360° in order to obtain a θ with +ve value.

- **Case5:**

For the start point (S),

1. if $x_s = x_c$ then either $y_s > y_c$ → A=90°
   or $y_s < y_c$ → A=270°
2. if $y_s = y_c$ then either $x_s > x_c$ → A=0°
   or $x_s < x_c$ → A=180°

For the end point (E),

1- if $x_s = x_c$ then either $y_e > y_c$ → B=90°
   or $y_e < y_c$ → B=270°
2- if $y_e = y_c$ then either $x_e > x_c$ → B=360°
   or $x_e < x_c$ → B=t80°

2- C.W. Circular interpolation:

This type of interpolation is obtained by applying the preparatory function of G2. To shape a circular path with C.W direction, a start point (S) with start angle (A) and in end point (E) with end angle (B) must be specified. In addition the coordinates of the center point of the circular path (point C) must also be given. For C.W interpolation the angle t9 is also required to be positive value. The angles A&B are used to determine the A & B angles, which are measured in C.W direction. Figure (12) illustrates such principle. Graphs of the suggested and employed cases of the C.W interpolation are shown in Fig.(13). The conditions of these assumptions are: -

- Case 1:

$$x_s < x_c \text{ And } y_s > y_c \rightarrow \bar{A} = 180^\circ + \tan^{-1}\left(\frac{y_s}{x_s}\right)$$

$$x_e > x_c \text{ And } y_e > y_c \rightarrow \bar{B} = 360^\circ + \tan^{-1}\left(\frac{y_e}{x_e}\right)$$

- Case 2:

$$x_s < x_c \text{ And } y_s < y_c \rightarrow \bar{A} = 180^\circ + \tan^{-1}\left(\frac{y_s}{x_s}\right)$$

$$x_e < x_c \text{ And } y_e > y_c \rightarrow \bar{B} = 180 + \tan^{-1}\left(\frac{y_e}{x_e}\right)$$

- Case 3:

$$x_s > x_c \text{ And } y_s < y_c \rightarrow \bar{A} = -\tan^{-1}\left(\frac{y_s}{x_s}\right)$$

$$x_e < x_c \text{ And } y_e > y_c \rightarrow B = 360 + \tan^{-1}\left(\frac{y_e}{x_e}\right)$$

- Case 4:

$$x_s > x_c \text{ And } y_s > y_c \rightarrow \bar{A} = 360^\circ + \tan^{-1}\left(\frac{y_s}{x_s}\right)$$

$$x_e > x_c \text{ And } y_e < y_c \rightarrow \bar{B} = -\tan^{-1}\left(\frac{y_e}{x_e}\right)$$

- Case 5:

For the start point (S),

1. if $x_s = x_c$ then either $y_s > y_c$ → $\bar{A} = 270^\circ$
   or $y_s < y_c$ → $\bar{A} = 90^\circ$
2. if $y_s = y_c$ then either $x_s > x_c$ → $\bar{A} = 0^\circ$
   or $x_s < x_c$ → $\bar{A} = 180^\circ$

For the end point (E),

1. if $x_s = x_e$ then either $y_e > y_c$ → $\overline{B} = 270°$
   or $y_e < y_c$ → $\overline{B} = 90°$
2. if $y_e = y_c$ then either $x_e > x_c$ → $\overline{B} = 360°$
   or $x_e < x_c$ → $\overline{B} = 180°$

For all the cases,

$A = 360 - \overline{A}$, $B = 360 - \overline{B}$

If A< B then A is set to A+360° in order to get t3 with positive value that is θ = A-B Figure (14) shows the interpolation algorithm and the vectorization procedure for this type of interpolation.

4.3 Simulation Program

A procedure for generating path simulation is developed to allow the user to display the cutting path on the computer screen before applying real cutting process. This would facilitate visual check of resulting path correctness to be cut in order to avoid any errors thatmay occur due to calculation or programming. The shape is simulated using graphic commands applied to the path coordinates data file as follows:

The monitor screen is usually a rectangular shape, hence, the number of picture elements (pixels) in width (i.e. number of screen columns) differs from that in height (i.e. number of screen rows), consequently the plotted graph must be corrected by applying the ratio (Screen Aspect Ratio (SAR) /Monitor Aspect Ratio (MAR)) [IS] where,

SAR = No. of screen coltmms/ No. of screen rows,

MAR = monitor widlh/monitor height

Fig. (15) shows the developed simulation procedure algorithm.

4.4 Position Measurement and Readout Procedure

This procedure accomplishes the position measuring fm~ction which presents both updating and the instantaneous position readout.

The developed procedure aims to give:

1-Displacement feedback information to facilitate computing the next movement along the path. The information is fed back on-line continuously.

2-Reat time display of both axes coordinates.

The procedure is able to receive and analyze the counting signals that are transmitted by the used hardware position counting circuit. The algorithm receives two signals from the position counter circuit for each axis. The signals are presented in a digital form, one of the signals present in the incremented movement pulses, while the other signal indicates the counting direction (whether +ve or -ve).

The down type counter used is of 16 bit; hence, the number of counting stages is from 65535 down to zero.

The conditions used in the processing of the received signals are as follows:

Assuming,

initial position values (IP) = 0

initial counter values (IC) = N

where N is any number within the range of 65535 → 0

current counter value (CC)

current position value (CP)

direction indicator (dir) is:

0 for +ve direction

8 for-ve direction

For positive movement direction:

If current counter < initial counter, then;

current position = initial position + | initial counter- current-counter |

If current counter > initial counter, then;
current position = initial position +| initial counter - (65535-current counter)|
For negative movement direction:
If current counter < initial counter, then;
current position = initial position- | initial counter -current counter |
If current counter > initial counter, then;
current position = initial position- |initial counter-(65535-current counter)|
If the current position = initial position, it mean no motion was happened.
The flowchart of this algorithm is given in Figure (16).

4.5 Interfacing / Driving Program

This program accomplishes the functions of motion driving and the interfacing between both the developed hardware and software systems, in addition to control the I/O ports of the two interfacing boards.

The program consists of four sub-programs. Its input is a data file that contains interpolated-vectorized path coordinate values. The four sub-programs are briefly discussed below.

4.5.1 Speed Calculation Sub-Program

In this sub-program, the user inputs the required feed rate (mm/s), then the program calculates the equivalent motor r.p.m, speed and obtains the slope relative to the current (actual) position from the slope modification sub-program (section 4.5.4). Tile calculated slope value is used to compute tile two axes motors speed. The motor speed would have a speed ratio relative to the obtained slope value in order to acquire the correct path. The co~puted speed will then be sent to each of the motor driving sub-program (section 4.5.2). Figure (17) shows a flowchart of this sub-program.

4.5.2 Motor Driving Sub-Program:

This sub-program gets the two axes speed values from the speed calculation sub-program, and converts them to equivalent binary numbers respectively, then, sends each of the binary form to the specified motor, through the I/O motor interface card, using the specified port address. The speed values are then converted to relative analogue sign~l in accordance with the used DAC's input ports and speed ranges.

The output port of this sub-program includes the following:

-Energizing the motor's output voltage relays.

-Energizing the PPI chip..

-Sending out tile calculated speed values that are converted finally into voltage by the DAC, these voltages are equivalent to the calculated speed relative to the slope of the desired path.

The principle of motor driving used is that when turning on the motor, it still works in this value until change occurs. Figure (18) shows the block diagram of this sub-program.

4.5.3 Position Measuring System Interface Sub-Program

This program is designed to receive the counter counts along with their direction status from the position measuring interface board via the computer bus. The given data are sent to the software controller of the counter circuit, (section 4.4), in order to achieve the position measurement and readout. This sub-program in addition to accomplishing the function of controlling the input counting signal ports, emits via the output ports the required numbers in the form of digits for loading the counter chip registers with maximum counting numbers. Figure (19) shows the block diagram of this sub-program.

4.5.4 Slope Modification Sub-Program'

This sub-program is used to calculate the slope of two point coordinates, one of them is got from the generated path data file and the other is obtained from the measuring system interface sub- program,, which represents the actual current position. The slope is calculated in order to modify the path position because of resulting difference between the previous calculated path slope and the current position slope, which may appear due to the mechanical effects or resolution of movement and measurement accuracy. The condition of calculating the slope which represents an inclining angle (8) is the same conditions for calculating the slope of the linear interpolation algorithm, (section 4.2.2.a and Figure (10)).

5. Results of the Developed System Testing

This section demonstrates results of the developed system. Many experimental trials were executed using proper cutting process to ass'ess the potential of the system. The following sections discuss the results obtained.

5.1 Simulation and Calibration

Results of the generated contour path obtained from the developed system were simulated graphically on screen using the specially developed routine. Because of the viewing screen ratio correction used to calibrate the simulated shape image (section 4.3), results indicate that plotted image exactly matches relative draft of the drawing. This would assure that any desired contour shape could be achieved with accepted accuracy and; therefore, any error in the generated path, (which may occur due to incorrect calculation of point coordinates or due to a mistake while part program editing), could be readily noticed in order to correct the related part program. A scaling function is included in the algorithm advantageously, thus any shape size can be simulated clearly.

5.2 Generated Path Testing

A procedure tbr testing the generated path of contour shapes was implemented by applying the generated path data file to a proper CNC controller of an existent-milling machine. The path data file contains the coordinates of the interpolated / vectorized path units arranged in blocks of part program. Tile resolution of the resulting path depends'upon tile discretization step, which represents the used Basic Length Unit (BLU) value. This testing procedure was conducted to evaluate the smoothness of the generated path practically using a proper CNC milling machine which has reliable control system, thus the contour of the machined part presents the potential of the developed path generation algorithms.

Results of trails showed excellent dimensions matching between required contour shape and the machined part This would indicate that the developed path generation algorithm could be used with confidence to achieve all desired shapes, and the discretization approach of path into vectors is a valid technique for linear and circular interpolation.

5.3 Position Measuring System Testing and Evaluation

This system was tested by driving manually the sliding mechanism to generate displacement signal feedback. Each movement axis was tested individually and the resulting feedback signal which gives the number of emitted encoder pulses processed and calibrated to make each pulse equivalent to one unit of length. Both positive and negative directions of motion displacement were tested and good responses were obtained.

The system was also tested using the motion driving system. Various ranges of motor- driven movement speed were attempted. The achieved match between the two sotSware systems, (measuring and driving software), showed good synchronization of both motion and measurement readout instantaneously. Experimentally, the measurement system sensitivity for very low movement feed rate (such as 0.1 mm/s) was verified and the system readout prov!ded the required feed back clearly.

5.4 Motion Path Implementation

This section discusses the motion path implementation and testing. Part programs for contour shaped samples were prepared using accurate path calculations. Two alternative control loop approaches namely open loop and closed loop were applied to achieve path implementation. The following two sections present the results of the conducted tests.

5.4.1 Time Control Function (Open Loop)

This scheme employs the time function -open loop control - to control the used D.C servomotors. The open loop control principle has no access to any real time information about system performance because no feed back information is received [14].

The generated path data file of each contour shape was processed by software using a given feed rate value to produce required binary values that match the interpolated / vectorized motion path coordinates in order to feed the two movement axes servomotors drivers. The feeding time constant, (time needed for sending out the motion data via output po,ts), was calculated to be proportional to both vector length and feed rate values, thus the resulting data file contains feeding time constant values for each vector length value which is basically, equivalent to the previously set BLU.

An experiment was conducted to achieve the path movement for a 45° triangular shape. Results of early trials showed noticeable deviation from required shape hence, a calibration factor was established to compensate for resulting errors which may occur due to motor driver behavior [16]; therefore; satisfactory results were obtained. Additional experiments were followed by changing the feed rate values, hence, the feeding time constant was also changed proportionally. Results proved acceptable generated path when using relative calibration. Hence, for each feed rate value, a calibration procedure should be accomplished in order to determine related feeding time constants.

Applying this procedure for each axis of motion, the feeding time constant at every feed rate value would be obtained practically and used to calibrate the system for confident later usage. Thus, the velocity calibration parameters would be fed forward to the applied control loop technique to elimhlate deviation error [17].

Real cutting processes were applied to cut a' set of sample shapes. Accuracy of ±1 mm was achieved for all cut shapes using a BLU value of 3 mm.

5.4.2 Feedback Control Function (Closed Loop)

The closed loop control principle is usually achieved by real time computation, hence, the system should be on-line to accomplish feed back calculation for error compeasatio [18].

The position measurements received from the position measuring unit were used in the developed system to compensate for path error by compenates are computed relative to the actual value, hence, the next position coordinates are computed relative to the actual received feed back position measurement. A sample contour shape, Figure (20), was verified successfully using closed loop control scheme.

Each motion axis was calibrated separately using relative constant feeding time in order to obtain accurate motion path with each BLU value. At each end of vector movement, instantaneous computation of the length of the next vector according to the received actual measurement was obtained in order to eliminate (or reduce) the resulting path error.

BLU values were implemented to achieve the contour shape. The shape was verified ten times, where for each time motion path was generated using different BLU value. The real path coordinates were recorded viathe position measurement system as feedback signals for comparison with the theoretically calculated (generated) path in order to evaluate the resulting shape path and system performance. The feed rate used was 4 mm/s. Results showed that Long BLU value hfi. s a negative effect on the generated path resolution because fine details of components might be lost. This could be clearly noticed when cutting components with sharp edges or highly curved profiles, hence, the selection of BLU value should be related to the feed rate value used, since using high feed rate would not leave enough time for computing on-line error compensation; therefore, if small BLU values were used higher path error might result. In addition, using large BLU value would limit the resulting path accuracy due to open loop variables, large BLU means longer vector length and complete contour path would require fewer vectors to be described and achieved, on the other hand, using small BLU value may produce an accumulated resolution error due to inadequate real time computation, and to the system response characteristics used .For the developed system, results show that the optimum range of BLU would be in the range of 3 to 5 mm.

6. Discussion and System Evaluation

The manipulated variables affecting resulting contour accuracy using the developed CNC system are defined as motor driver response calibration factor and feed rate calibration factor. The problems associated with the selection of calibration factors are handledby software'modification though these problems are a.rising from components of the developed hardware system.

A starting shock is noticed at the beginning of each operation for both motors, i.e. at the starting up of the motor rotation. This shock may affect the resulting path resolution and may also damage the hardware (electronic and mechanical parts) used, hence, shock eliminating subroutine was developed and applied which sends out zero speed signal at the start ofeach axis motion in order to prevent the abrupt change of output pulsating rate to the servomotors drivers.

Early tests indicate that the specification of the used driving systems differ when applied and coupled to the driving mechanism. The difference ratio was measured practically and found to be 30%, i e. the net speed of both axes motor is 70% from the calculated and set to the servo drivers. This state was overcome by increasing the entered feed rate value by 30% from its computed value.

The sliding positioning mechanism used which is based on rack and pinion is preferable for long movement machine axes because that drive stiffness is independent of the stroke length, however, the degree of accuracy in positioning may be limited when compared with other more expensive mechanisms like ball 0screw. The used mechanism type is adequate for use in thermal cutting machines and could be used with confidence to achieve the tolerances associated with this type of cutting.

Calibration of feed rate values was performed by practical measuring the swept displacement stroke using timer watch and compensating the error computationally by software.

The system affords flexibility of using different resolution encoders for the position measurement system because signals generated from encoder are processed and calibrated by software to accommodate the resolution used to enable tree path control operation.

The approach of software processing to replace the specialized hardware components which was investigated and applied, in this work presents an advantageous technique to reduce installing and maintenance cost and simplify the hardware system.

The high resolution of the used DACs (12 bit). provides a wide range of controlling values (equivalent to 2048 stages of velocity), thus facilitating the achievement ora Wide range of feed rates, which allows the application of small and large BLU vaiues to enable th~ obtaining of best resulting path resolution.

Interface between the used PC/XT type computer with the developed hardware (driving and position measurement systems) is constructed 'using I/O interface cards which were designed and built specially to accommodate the functions and characteristics of this system. These electronic cards were connected to the computer using the available expansion slots that facilitate the link to tile PC-bus and allow successful data acquisition and signals generation. The software to control the I/O interface unit was developed and used to acquire (and send) required data from (and to) the address ports used.

Motion path simulation of part programs as graphical display showed great visual aid to enable tile user to correct any errors before applying real cutting process. Such approach is included in the developed system and applied beneficially.

Real flame cutting operations for contour shapes were implemented using both control schemes, open loop and closed loop controls, the resulting shapes accuracy indicate the success of using this system for thermal cutting processes. Figure (21) presents photographs of contoured shapes cut using the two alternative techniques.

Results indicated that applying open loop control scheme to D.C servo motors for non- contact cutting processes e.g. thermal cutting processes that inhibit constant torque through execution, may present a valid technique to minimize the hardware, used simplify the I/O interface circuits and reduce costs.

7. Conclusions

In this work, development of CNC motion system for thermal cutting machine has been approached and investigated. Both software and hardware components were implemented in the developed system to achieve the goal. Interfacing the capabilities of the PC with related machine components to develop a numerical control for the developed CNC thermal cutting systems, was performed successfully, and replacement of some specialized CNC hardware by equivalent software was achieved beneficially. The methodology of this work indicates that the control scheme of CNC machines' could be achieved by software to reduce the cost of manufacturing and maintenance of CNC system hardware which are relatively high. In addition this would increase production flexibility by allowing change in the developed software to meet manufacturing requirements. Hence, PC control software for CNC system could be developed with flexibility to facilitate upgrading, allow features adding, and accommodate simultaneous control of other driving units.

Sets of tests were performed to determine the dynamic characteristics of the developed system. Real flame cutting operations were implemented. Results indicate the validity of the developed procedures. By computer simulation and experiments, the effectiveness of the proposed system was verified. The two control loop schemes, open loop and closed loop controls, were investi'gated and implemented in the developed system without any physical hardware change. Results of the performed system tests have proved the validity of the proposals and would encourage further system development to meet the industrial requirements for such machines. The open loop control proves effectiveness, especially when the system velocity variables are added for forward compensation to reduce errors, hence, the developed controller by this procedure operates as a fonvard control approach.

The cutting feed rates were designed for tile developed system to meet dut recommended for thermal cutting procces for both, flame cutting that needs relatively low cutting speeds, and plasma arc cutting requires relatively high cutting speeds.

Position measurement sub-system are proposed and implemented to achieve closed loop control. Errors resulting from the mechanical components were reduced by calibration and processing which are implemented in the developed algorithms.

The integration of CAD and CAM systems via the developed software system is approached through the contour path generation and the graphical simulation algorithms to present the tool path of the desired pa.rt geometry. Results of application trials showed system validity in handling any shape geometry to bo thermally cut. Measurements of achieved contour b, hapes askT~red that shapes composed of lines and arcs can be cut with accepted accuracy, hence, industrial construction of CNC thermal cutting systems based on the procedures presented in this work is applicable.

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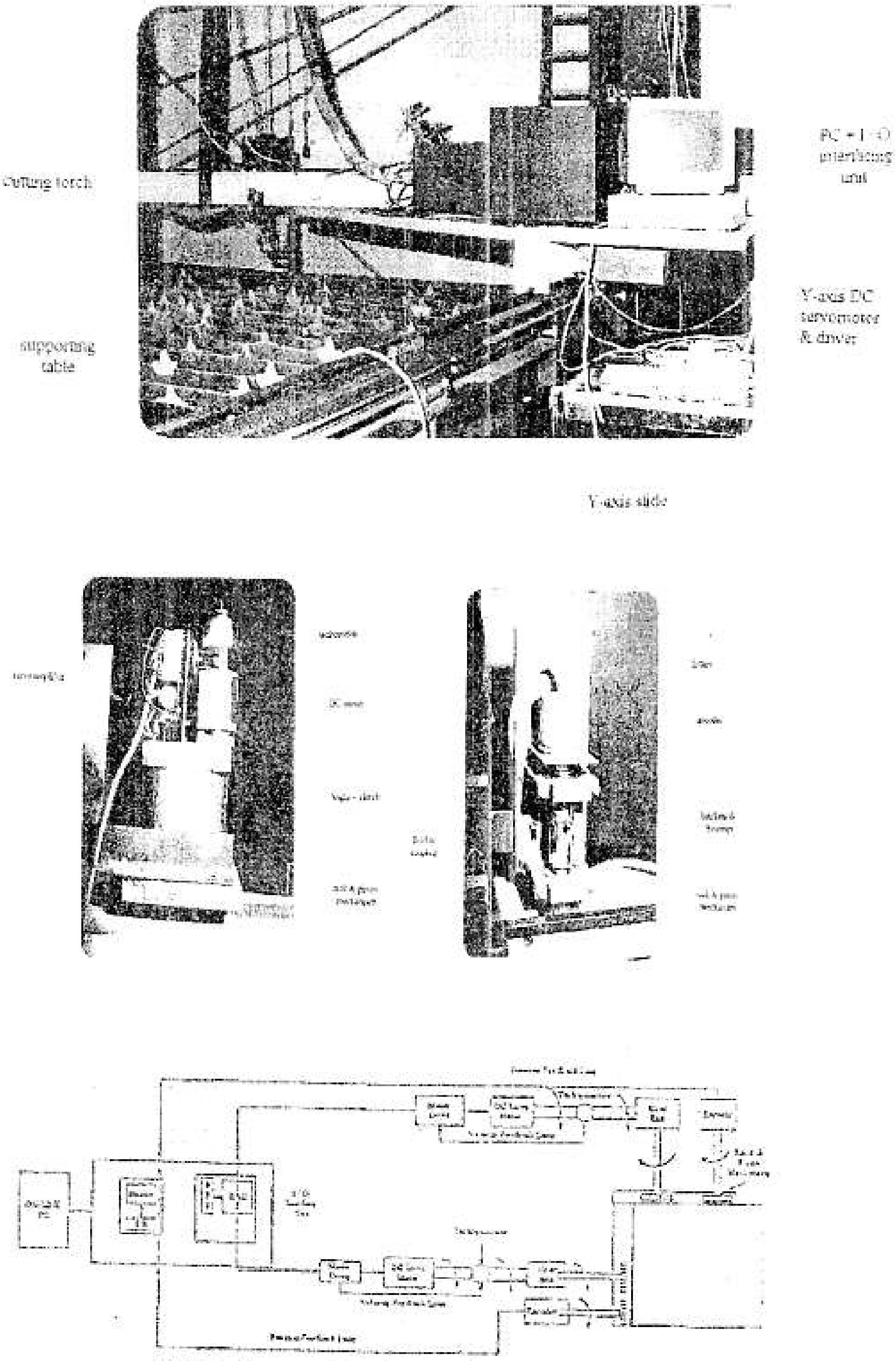
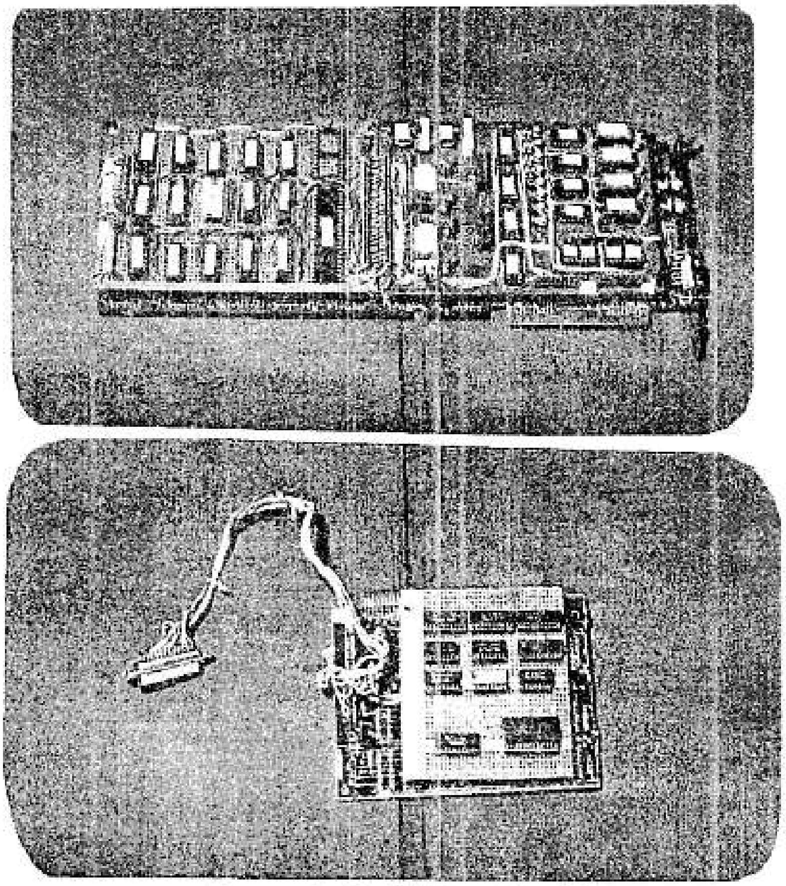


d) Block diagram of the developed machine hardware.

Figure (1) The Developed Machine Components



Figure(2) The I/O Interface Unit

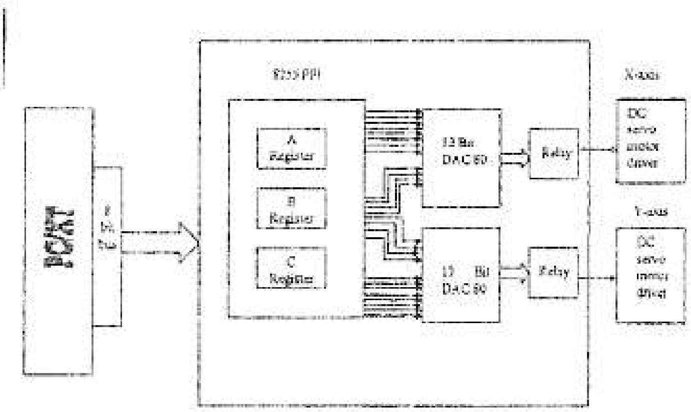


Figure (3-a) Simple Schematic Diagram of the Built Motor I/O .

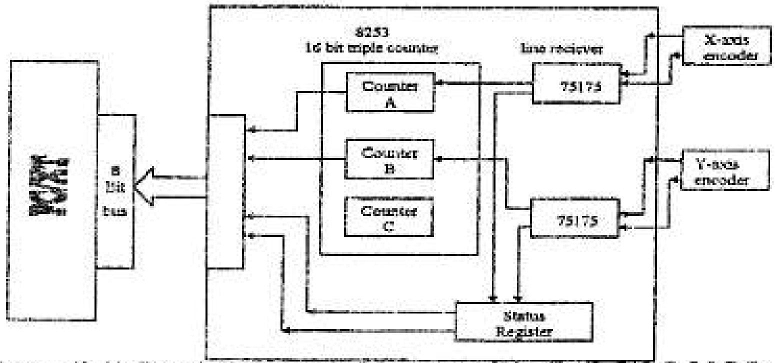


Figure (3-b) Simple Schematic Diagram of the Built I/O P.M.S Interface

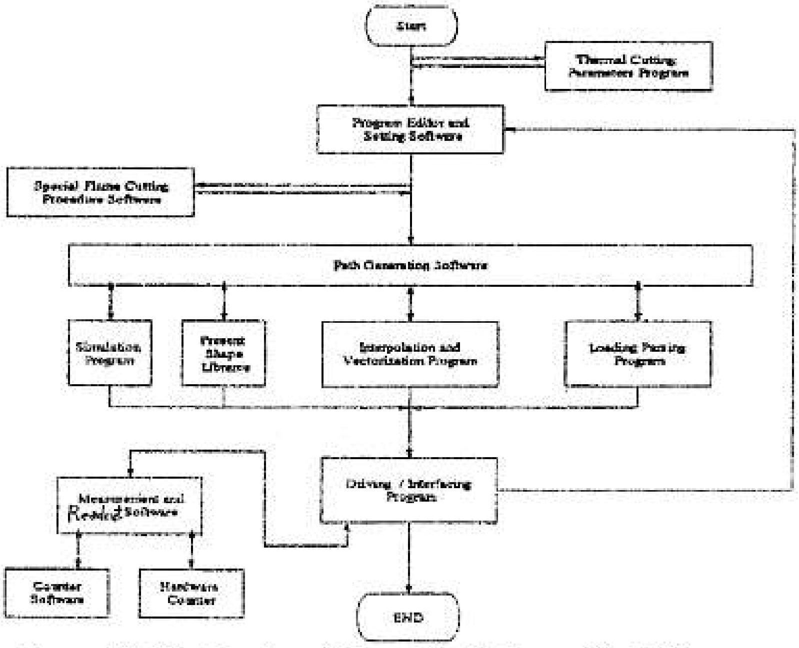
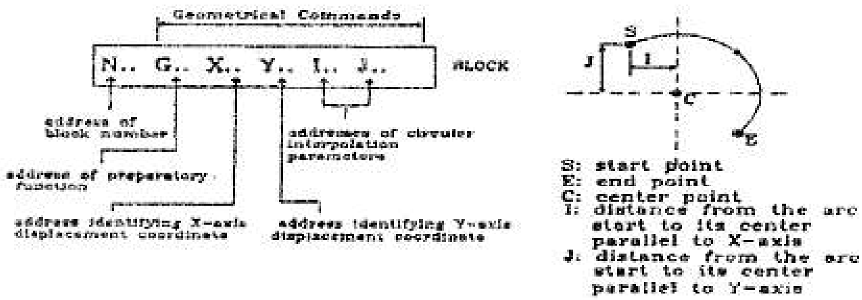


Figure (4) The Developed Controller Software Block Diagram.



(a) Block Entities

(b) Interpolation

Figure (5) Part Program

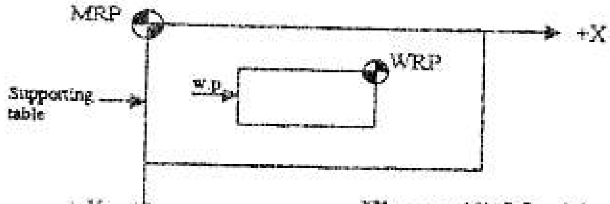


Figure (6) Machine Co. System

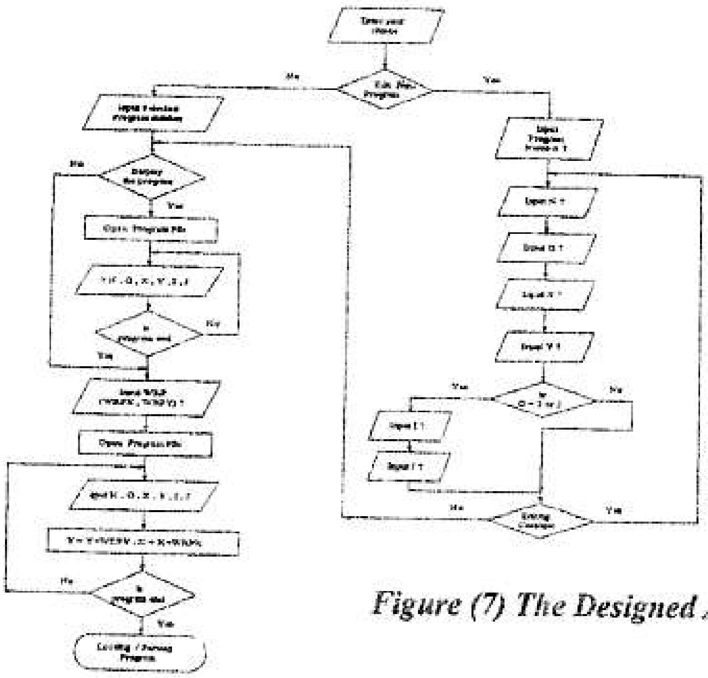


Figure (7) The Designed Algorithm

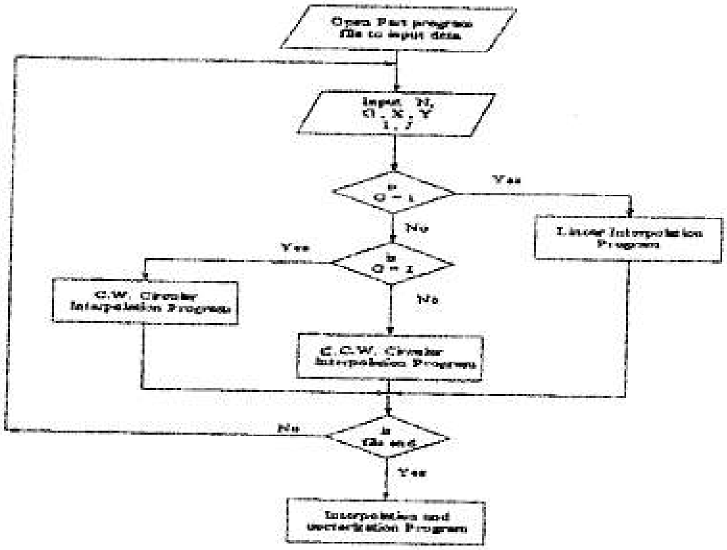


Figure (8) Loading/Parsing Program

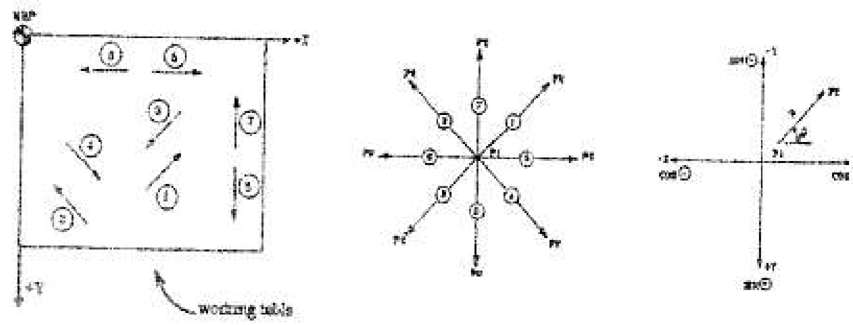


Figure (9) Eight Assumptions

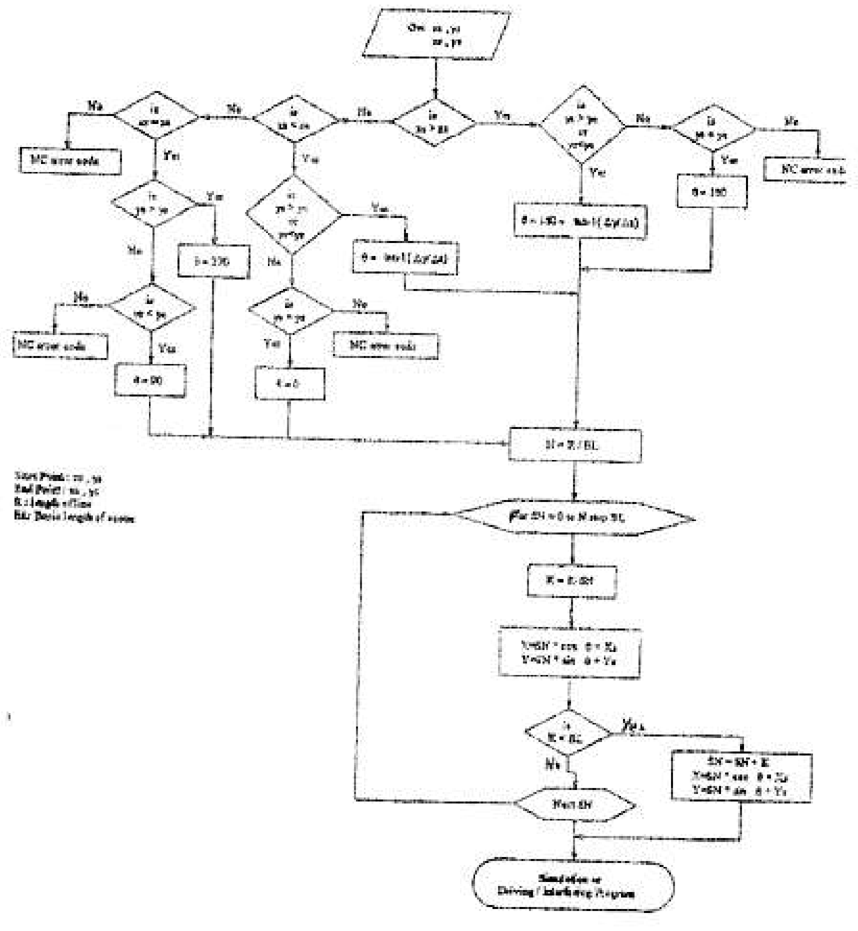


Figure (10) linear Interpolation

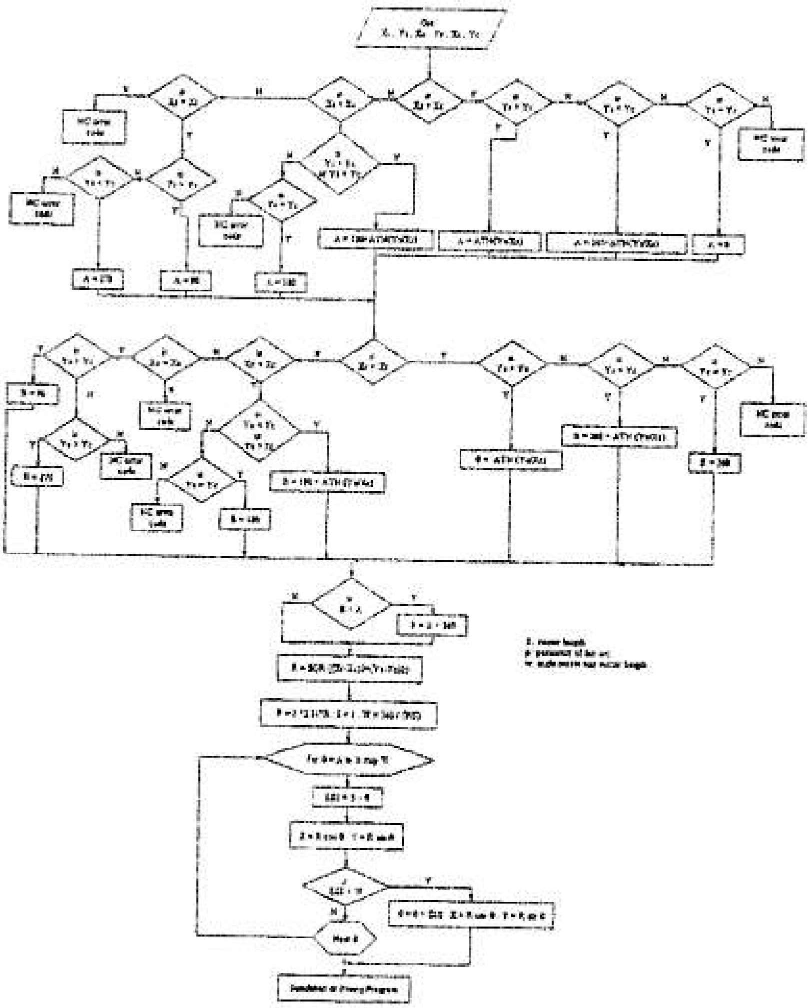
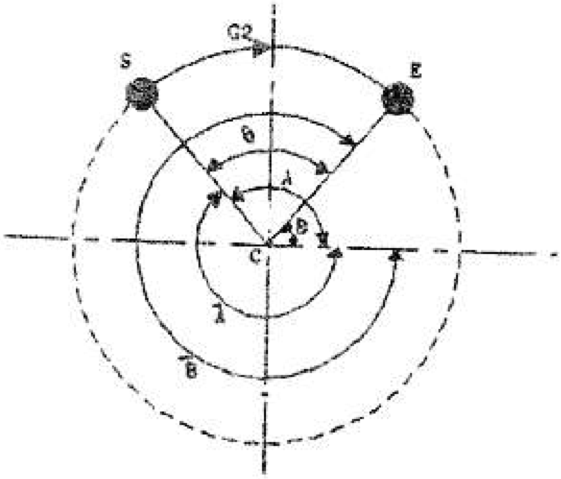
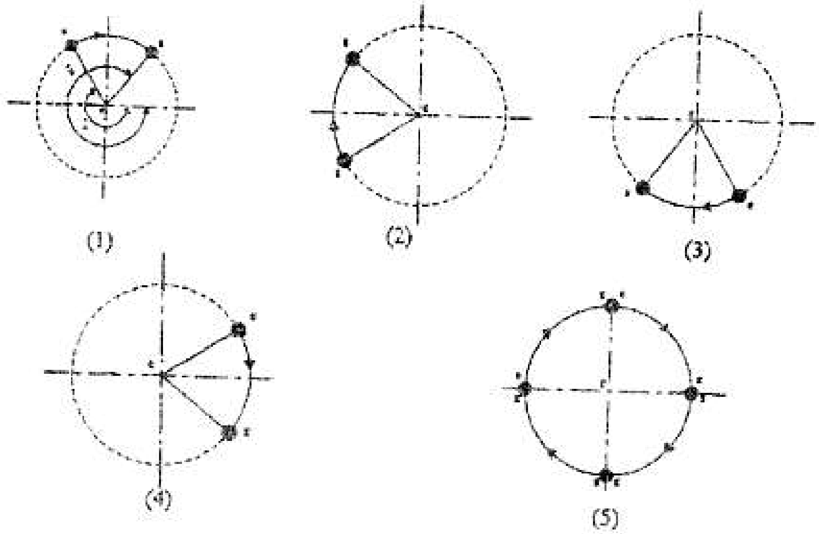


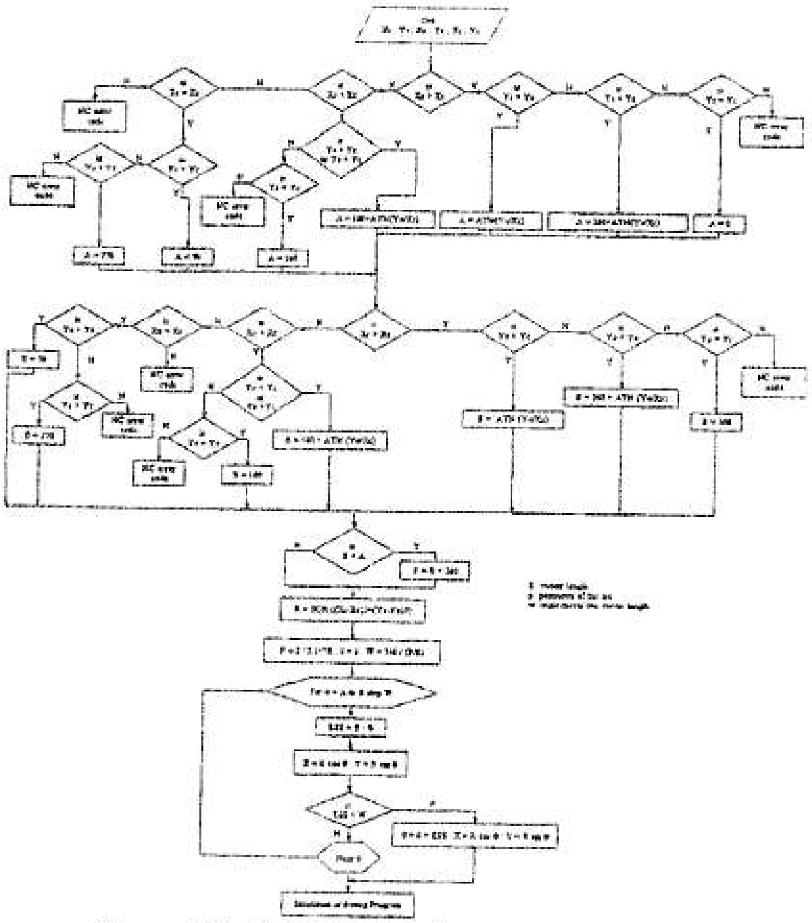
Figure (11) C.C.W Circular Interpolation



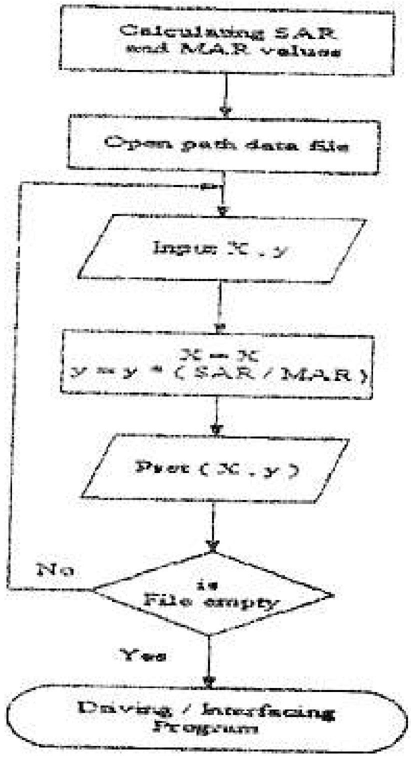
Figure(12) C.W Circular Interpolation



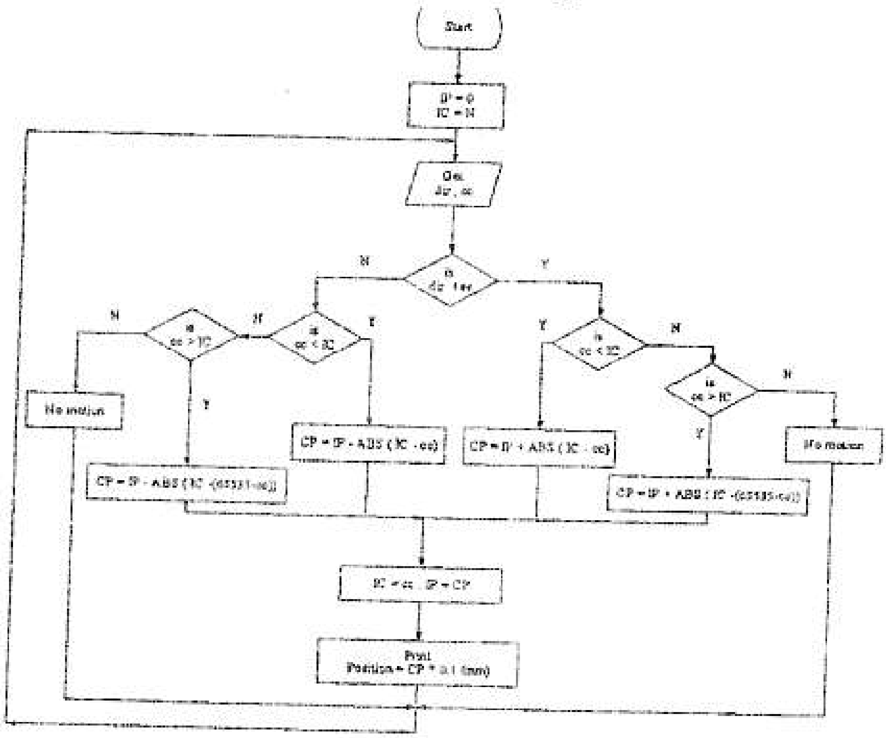
Figure(13) Suggested C.W Circular Interpolation



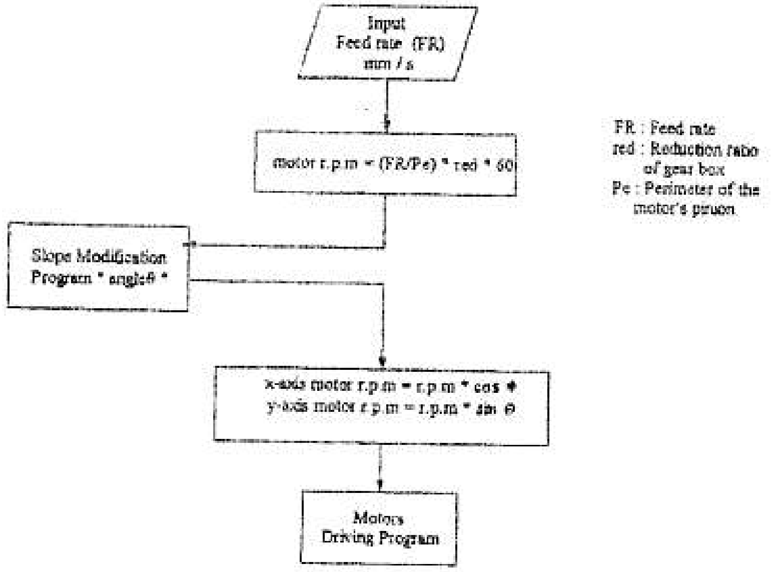
Figure(14) C.W Circular Interpolation Vectorization



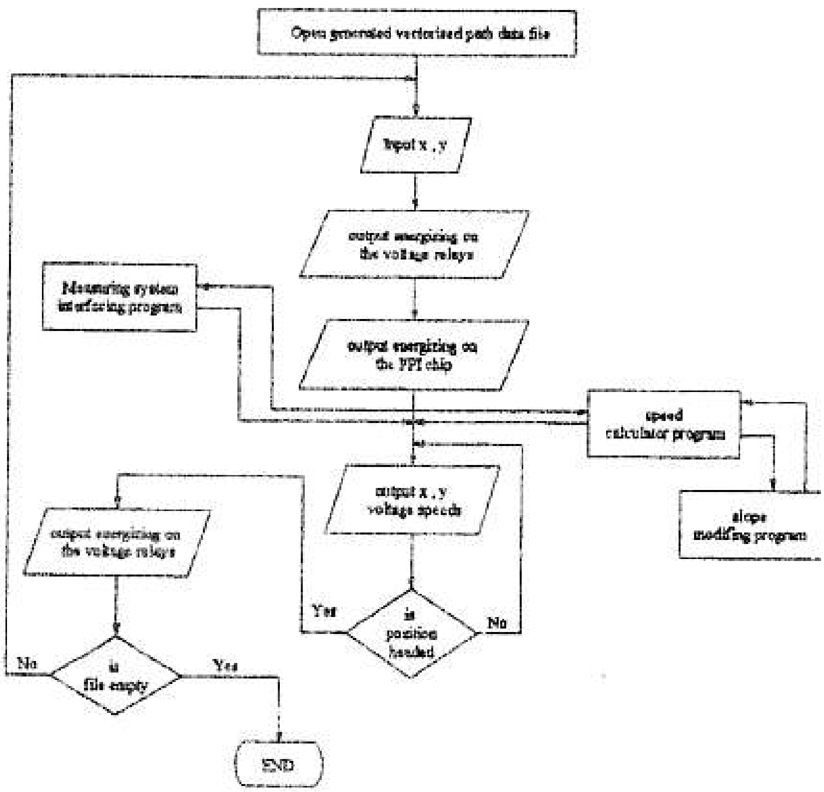
Figure(15) Simulation Program



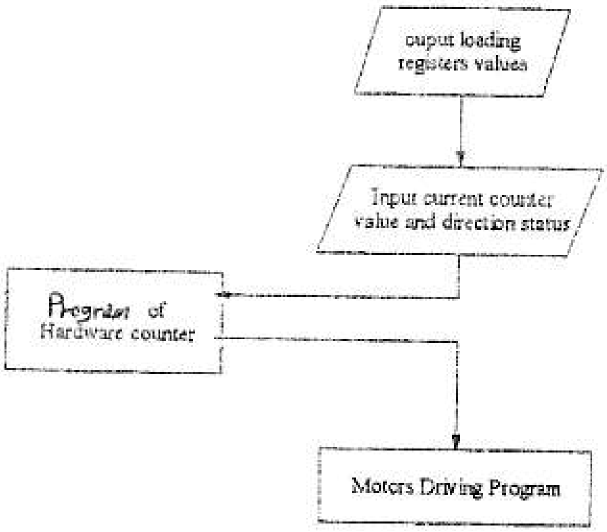
Figure(16) Hardware Counter Positioning Algorithm



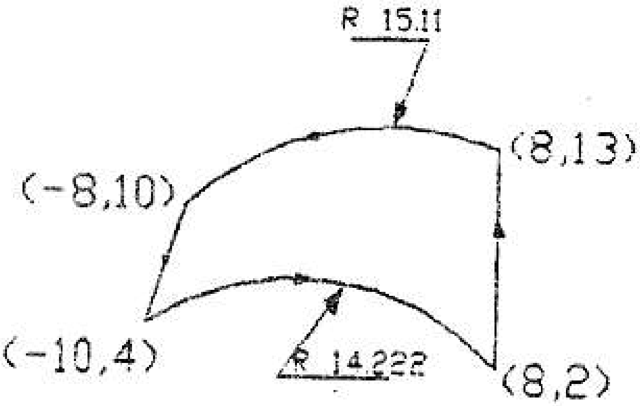
Figure(17) Speed Calculation



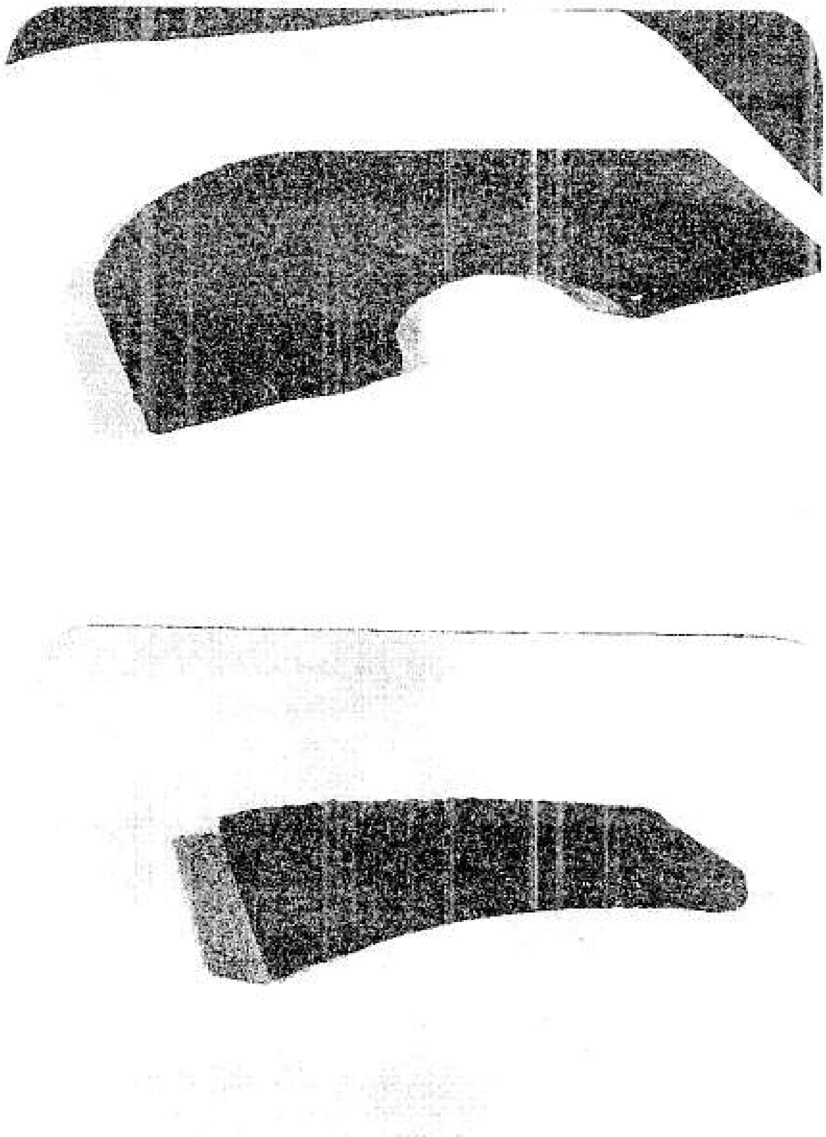
Figure(18) Motor Driving Sub-program



Figure(19) Position Measurement System



Figure(20) An Example of Implemented Contour using Closed Loop Control



Figure(21) Example Contour Using the Developed Machine