DATA ACQUISITION BASED COMPUTER NUMERICAL CONTROLLED (CNC) MILLING MACHINE

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ABSTRACT:

A study of data acquisition based computer numerical controlled (CNC) prototype 3-axis milling machine is presented. The mechanical construction, electrical drive circuits and the PC-based control system have been experimentally implemented in the Arab Academy for Science and Technology (AAST) control laboratory. A computer aided design (CAD) program has been developed using C-language to Off-Line draw the required milling shape and then On-Line control machine axis motions to get this shape on the work piece. The overall experimental setup construction and main parts are presented. Experimental results of the proposed system are demonstrated.

Keywords: *- CAD program, CNC machine, Data acquisition, Reversible drive and PWM.*

1. INTRODUCTION

The huge development in computer technology together with the rapid growing of data acquisition board manufacturing has introduced the PC-based data acquisition system as a simple and cheep control solution for some industrial systems. The demand for better accuracy in the manufacturing of complicated parts and the desire to increase productivity has developed robot and CNC industrial systems [1].

Manuscript received from Dr . A. F. Amer
Accepted on : 20 / 4 / 2002
Engineering Research Journal Vol 25,No 3, 2002 Minufiya University, Faculty Of Engineering , Shebien El-Kom , Egypt , ISSN 1110-1180

Servo drive systems, which utilize motors and power electronics, are commonly used to control motion of the CNC machines as they are designed to achieve precision and fast response to the demand signal variation [2]. DC motors still have some sort of solid ground in servo applications due to its versatile control characteristics while power electronic circuits are now widely used to control motor motion and bring about a significant improvement in the dc drive systems [3]. A generalizing approach for generating CNC motion profiles has been presented in order to perform given tasks efficiently [4]. An iterative learning controller has been proposed for precise tracking control of industrial robots and CNC machines [5]. In this paper, a computer-based data acquisition system together with power electronic circuits are proposed to control motor motions of the prototype 3-axis milling machine in order to perform required milling tasks.

2. OVERALL EXPERIMENTAL SETUP

The experimental setup, shown in figure 1, has been completely implemented in the control laboratory of Arab Academy for Science and Technology (AAST) using local available materials and equipments. The main parts of the setup are the mechanical construction, electrical circuits, the interfacing card and the personal computer (PC) as a controller. These parts will be demonstrated through the following sections.

2.1 Mechanical Construction

Figure 2 shows engineering drawings of the prototype 3-axis milling machine that has been completely designed and manufactured in the control lab. Three identical mechanical constructions utilize DC permanent magnet motors together with gear coupling and feed-screw mechanisms are used to control the motion of machine axes. The permanent magnet dc motor is used for its eventual availability with low cost and suitable performance to present applications. The coupling mechanism with feed-screw drives a load with linear motion from the rotating motor while the gear mechanism matches between motor and load torque–speed characteristic [6]. The work piece is fixed on a small table moves up or down along Z-axis due to the pre-determined depth. The turning machinery tool could be simultaneously moved (forward or backward) along X-axis and Y-axis to draw the required shape.

2.2 Electrical Circuits

The electrical circuits shown in figure 3 have been implemented to drive the motors using the control signals. The speed and position of X-axis and Y-axis should be simultaneously controlled in both forward and reverse directions to draw a required shape. This can be achieved using H-bridge chopper circuit fed from pulse width modulated (PWM) signal. Comparing a saw tooth signal with the required speed signal, determined by the computer, generates the PWM signal. The modulated signal is then fed to the chopper switches according to the state of direction and ON/OFF control signals. Motor speed is varied as a result of the change in the average voltage applied to the motor due to the duty cycle variation. In the H-bridge four-quadrant dc chopper, shown in figure 3.d and 3.e, two NPN transistors are used in the lower limbs while other two PNP transistors are used in the upper limbs. This configuration validates the use of a single supply source to drive all the transistors instead of different suppliers required when all H-bridge transistors are NPN types [7]. Since Z-axis is individually moved up or down to only determine the depth of milling process, position control is required but no speed control is needed. These requirements of Z-axis can be fulfilled using two reversing contactors as shown in figure 3.f. The of motor the turning machinery tool is switched on and off through isolating opto-coupler and contactor as shown in figure 3.g. For each axis, a rotating potentiometer is directly connected to the screw axis in order to measure the actual position. The dc output voltage of this analogue transducer is calibrated and fed back to the computer through the interfacing card.

2.3 Interfacing Card

A plug-in data acquisition board, C10.DAS08/Jr-A0 [8], has been installed and utilized to interface between the computer software and the electrical circuits in order to control all motors of the prototype machine. The board supports eight digital inputs, eight digital outputs, eight single-ended 12-bits successive approximation multiplexed 25μsec ±5V analog inputs and two 12-bits ±5V buffered analog outputs. Utilization of the data acquisition board is summarized in table 1.

2.4 Computer Control

A computer program has been written in C-language according to the flow chart shown in figure 4. The required shape is drawn using the mouse and keyboard then converted to data saved in a file. This process is done off-line. The computer then on-line controls the motion of all motors to get the drawn shape on the milling work piece. It should be noted that the system works in ON-OFF closed-loop position control using the computer while the speed is controlled through the external hardware PWM circuits in an open-loop fashion.

3. EXPERIMENTAL RESULTS

The experimental setup shown in figure 1 has been implemented and tested. Figure 5 depicts the experimental motor voltage and current waveforms when motor direction is changed from reverse to forward then back to the reverse direction. These waves are identical if the same test is carried out for any of X and Y motor drives. The voltage applied to the motor is pulse width modulated while the current is determined by the duty cycle hence the speed. From figure 5 it can be seen that the software program introduces a delay interval before any reversing operation. This delay reduces motor current at reversing hence protects motor windings and minimizes mechanical stress during the reversing operation. Experimental results of the system when being operated to draw a certain milling shape are shown in figure 6. Voltage and current waveforms for Y and X motors are shown in figure 6.a and 6.b respectively. The actual positions of Y-axis and X-axis are depicted in figure 6.c. Figure 6.d illustrates the actual and the required milling shape. From figure 6 it can be seen that X and Y motors are simultaneously controlled with different speeds and directions to get the required shape. The actual milling shape tracks the required shape with finite steady state error. This error could be minimized using linear, temperature independent position feedback sensors instead of the used rotating potentiometer. Better accuracy could be fulfilled if closed-loop speed control algorithm is implemented through the PC instead of the open-loop speed control applied in the proposed setup. This required additional sensors for speed feedback and software extension to include speed control algorithm.

4. CONCLUSIONS

Design, manufacturing, implementing and operating of a 3-axis prototype computer numerical controlled milling machine have been achieved in the control laboratory of the Arab Academy for Science and Technology. A personal computer supported with a data acquisition card has been utilized to Off-Line draw the required shape and On-Line control motion of machine motors to get this milling shape on the work piece. Reversible dc drives are experimentally implemented, using two H-bridge dc chopper circuits fed from PWM signals for X-axis and Y-axis while using two reversible contactors for Z-axis. Experimental results showed capability of the proposed setup to draw the required milling shape. Better accuracy could be achieved if actual speed is fedback to the computer and both position and speed closed-loop software algorithms are implemented.

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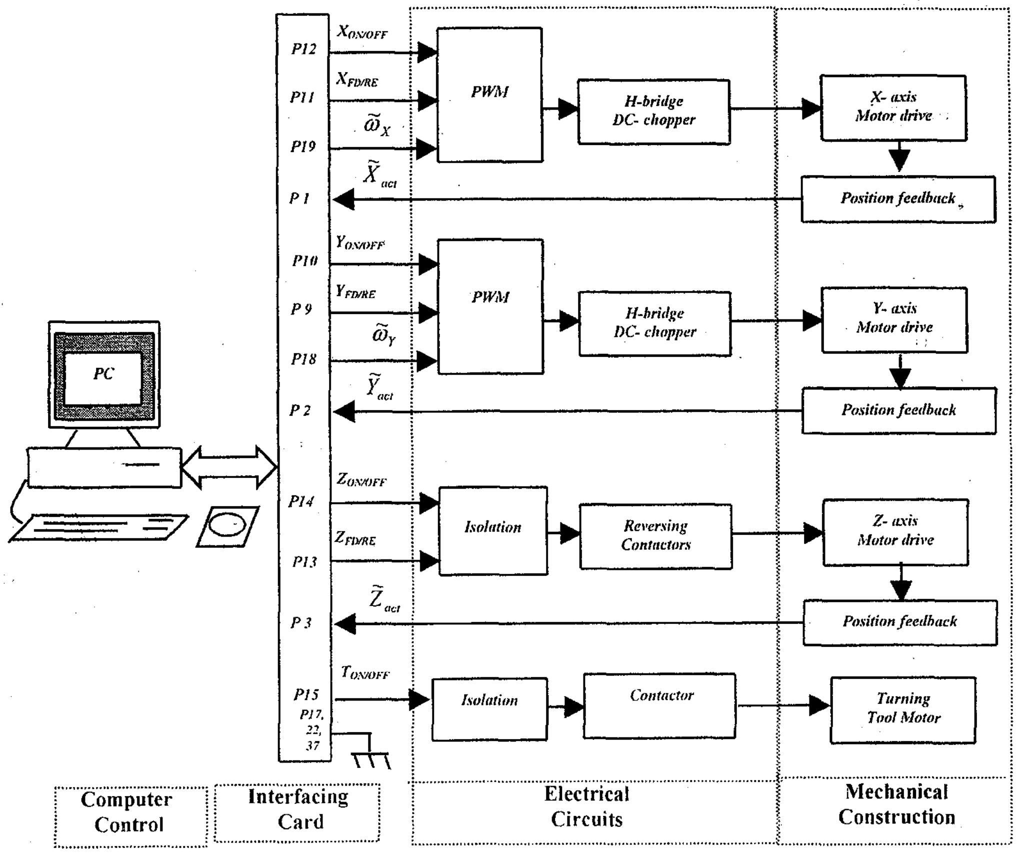
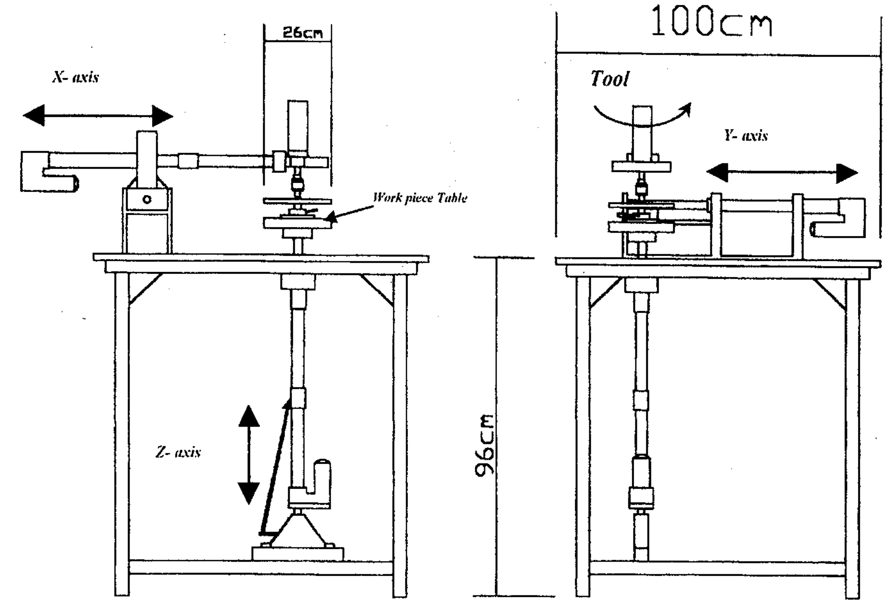


Figure 1. Overall experimental setup

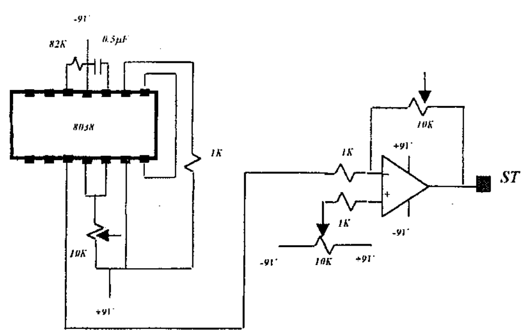
Pin	Category	Symbol	Function
1	Analog input	X_{act}	Actual position of X-axis
2	Analog input	Y_{act}	Actual position of Y-axis
3	Analog input	Z_{act}	Actual position of Z-axis
9	Digital output	$Y_{FD/RE}$	Direction control of motor Y
10	Digital output	$Y_{ON/OFF}$	Switch on / off motor Y
11	Digital output	$X_{FD/RE}$	Direction control of motor X
12	Digital output	$X_{ON/OFF}$	Switch on / off motor X
13	Digital output	$Z_{FD/RE}$	Direction control of motor Z
14	Digital output	$Z_{ON/OFF}$	Switch on / off motor Z
15	Digital output	$T_{ON/OFF}$	Switch on / off tool motor T
18	Analog output	ω_Y	Reference speed of motor Y
19	Analog output	ω_X	Reference speed of motor X

Table 1. Utilization of the data acquisition board

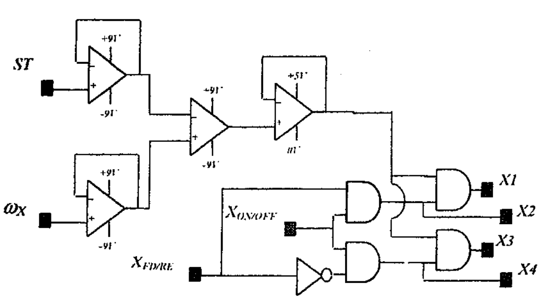


a) Elevation *b) Side view*

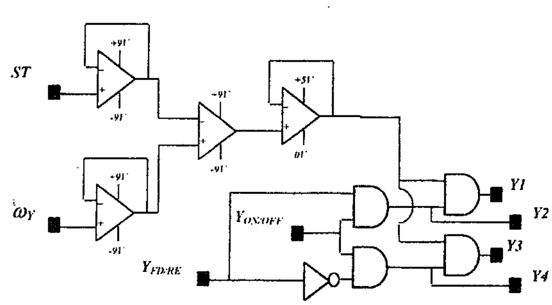
Figure 2. The prototype 3-axis milling machine



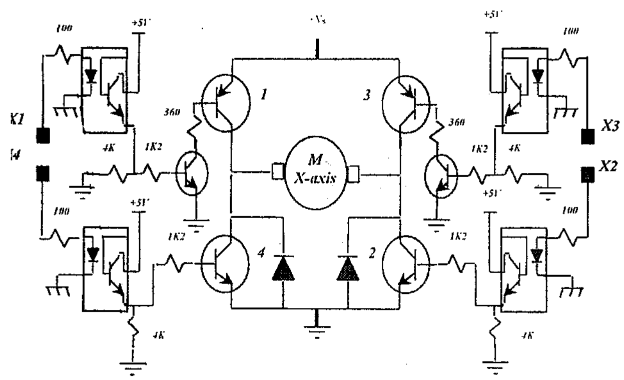
a) Saw tooth generator



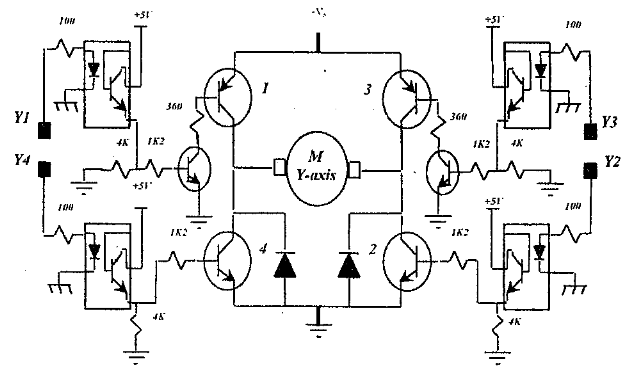
b) PWM for X-drive



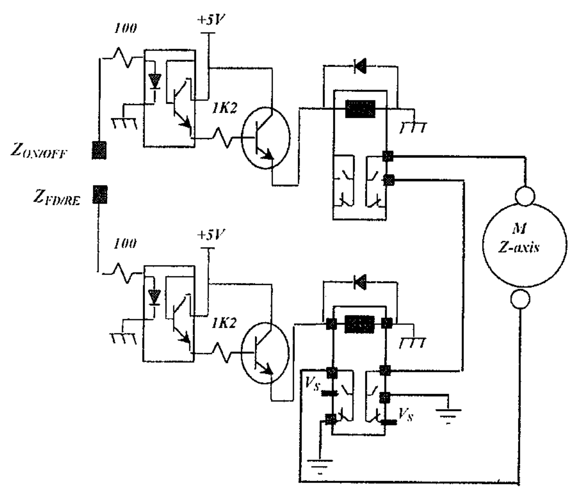
c) PWM for Y-drive



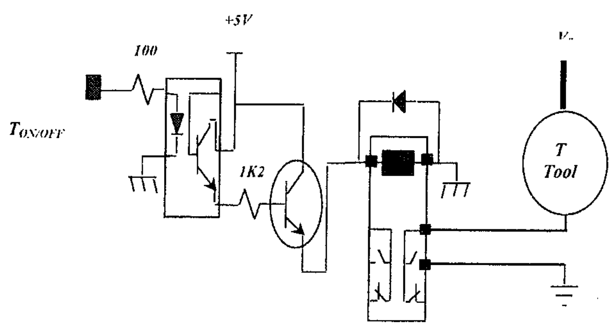
d) H-bridge for X-drive



e) H-bridge for Y-drive



f) Reversing contactors for Z-drive



g) Isolation for turning tool motor

Figure 3. Electrical circuits

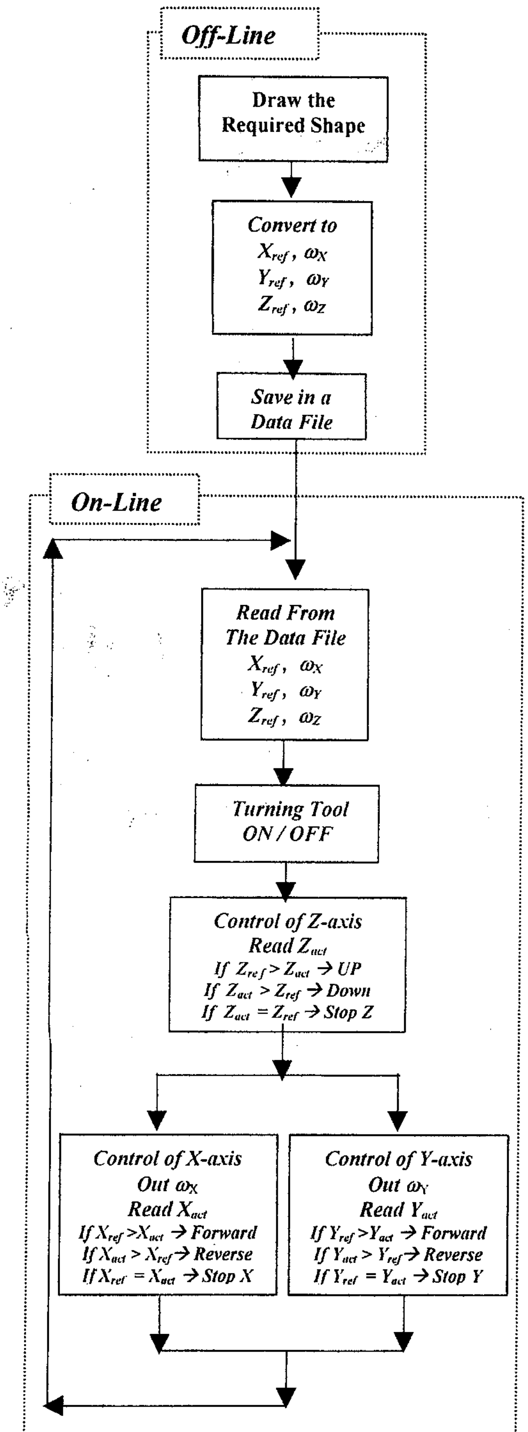


Figure 4. Program flowchart

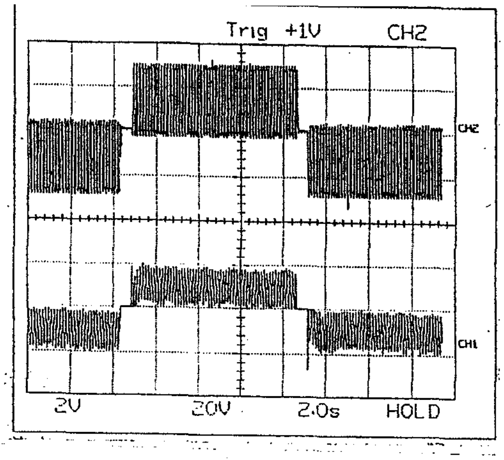
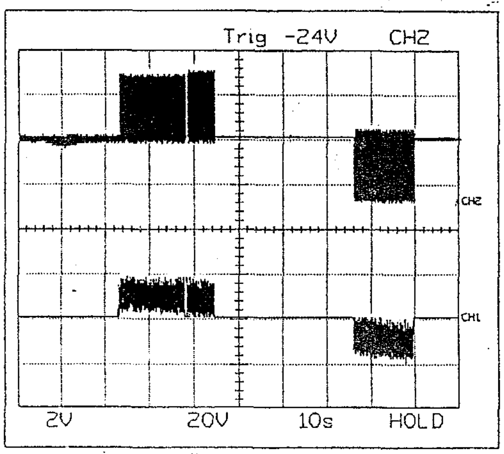
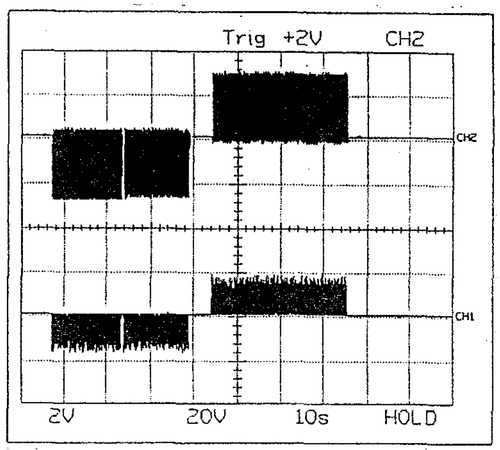


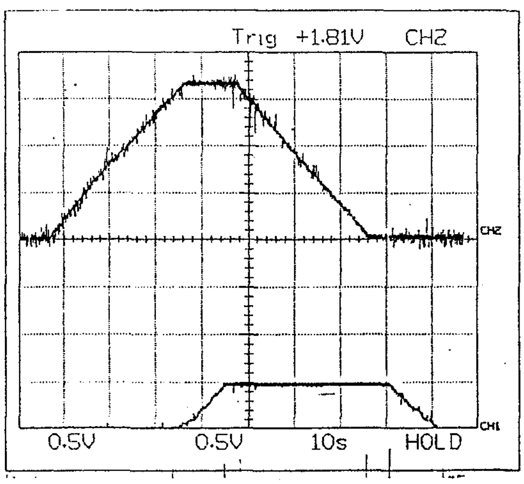
Figure 5. ***Experimental current (CH1) and voltage (CH2) waveforms at reversing for any of X and Y Drives***



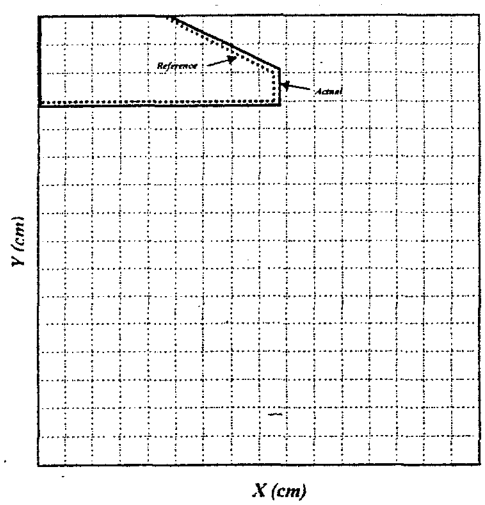
a) Current (CH1) and voltage (CH2) waveforms of Y-motor



b) Current (CH1) and voltage (CH2) waveforms of X-motor



c) Actual position of Y-axis (CH1) and X-axis (CH2)



d) Reference and actual milling shape

Figure 6. ***Experimental results for drawing a certain milling shape***

تصميم وتشغيل نموذج لماكينة فريزة تعمل بواسطة الحاسب الشخصي

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ابوقير — الإسكندرية - ج.م.ع

هذا البحث يعرض دراسة عملية واختبار معملي لتشغيل نموذج أولى لماكينة (فريـــزة) ذات محاور ثلاثية. يتم التحكم في تشغيل هذه الماكينة بواسطة الحاسب الشخصي المزود بكارتــة خاصة للربط بين أجزاء الماكينة المختلفة والحاسب. وقد تم تصميـــم و تنفيـــذ الأجـــزاء الميكانيكية والكهربية المختلفة للماكينة في معمل التحكـــم بالأكاديميـــة العربيـــة للعلـــوم والتكنولوجيا بواسطة الخامات المتوفرة بالأسواق المحلية.

وقد تم تصميم و تجربة برنامج كمبيوتري باستخدام لغة " C " وذلك لإمكانيـــة رســـم الشكل المطلوب تشغيله باستخدام الفأرة ثم تحويل هذا الشكل إلى بيانات للتحرك في المحـــاور الثلاثة. يقوم الحاسب بالتحكم في سرعة وأماكن المحاور الثلاثة تبعاً للبيانات السابقة وذلـــك لرسم الشكل المطلوب على قطعة التشغيل.

من خلال هذا البحث يتم عرض الأجزاء الرئيسية للماكينـــة وكذلـــك دوائـــر التحكـــم المستخدمة ورسم مسار تخطيطي للبرنامج الكمبيوتري المصمم في هذا البحـــث. وقـــد تم تشغيل واختبار هذا النموذج وكذلك عرض وتحليل النتائج العملية لهذه الماكينـــة في حالـــة تشغيل وتفريز شكل محدد.