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DESIGN AND IMPLEMENTATION OF MINI-WOOD ENGRAVING MACHINE

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Work Team

ABSTRACT

This Project discusses the CNC machines structure and its purpose of existence, then it shows the designing and implementing procedure of this machine starting from making a theoretical designation and selecting parts of the project and ending with arranging its working status.

This Report Contains an Introduction that describes the machine in general, the next chapter describes the hardware components used in the machine, the third chapter describes the software used to operate the machine and the fourth chapter includes the working procedure to implement the machine.

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Chapter 1

Introduction

1.1 General Background

Arabesque art consists of a series of repeating geometric forms which are occasionally accompanied by calligraphy. Ettinghausen et al. describe the arabesque as a vegetal design consisting of full and half palmettes as an unending continuous pattern. in which each leaf grows out of the tip of another. To the adherents of Islam, the Arabesque are symbolic of their united faith and the way in which traditional Islamic cultures view the world

Another wood carving in palestine was Olive wood handcrafts, where these workers make sculptural writings or images on a piece of wood. Hardworking and time consuming.

Therefore we aim from this project to find a way of producing these products with less time and more accuracy. figure 1.1 shows the main components of the desired working machine, where there are three dc servo motors that moves the head motor through axes x, y and z. and the fourth motor is the head motor, within a controlling system that gives the production aim as will be discussed in later chapters.

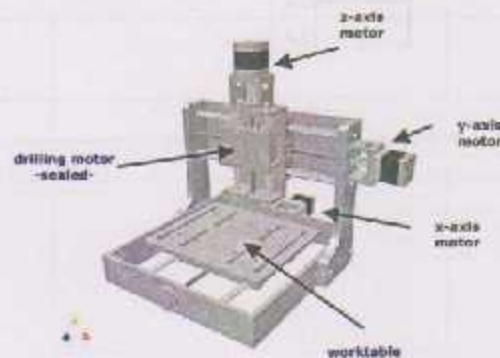


Figure 1.0.1 Machine Construction

1.2 Project Aim

- Reducing time working in peace of wood and accuracy work.
- Increase number of product in time unit.
- learning how to use stepper motor.
- learn how to make complete project contains electrical and mechanical system

1.3 Previous Studies

Similar Projects that worked on stepper type motors, defining softwares and designing them according to the motors types, However This project will use the latest technologies of working components such as software platform and DC stepper motors or interfaces which will give an enhancement on the overall production.

1.4 Financial Study

Item	Quantity	Cost/Qty (US\$)	Units price (US\$)
Stepper motor	3	150	450
A/C motor	1	150	150
Computer	1	150	150
Interfacing Board	1	250	250
Wiring and mountings	-	50	50
Lathe work	-	200	200
Total Price			1250

1.5 Schedule Time

This scheduling is desired for the working on the Introduction to graduation project

Number	Task	Start	End	Duration	Q1 - 2011			Q2 - 2011		
					January	February	March	April	May	June
1	design of mechanical body and selection of parts	2/1/2011	2/20/2011	13		■				
2	mechanical body fabrication	2/21/2011	3/20/2011	18			■			
3	Electrical Equipment Installation	3/23/2011	4/25/2011	25			■			
4	Testing the machine after combining its parts	4/26/2011	5/15/2011	14				■		
5	Report Writing	5/16/2011	6/2/2011	13					■	

1.6 Suggestions

The suggestions for developing the project in following steps are:

- using the project in a practical application or making PCBs.
- using servo motor in application that is used in feedback control systems
- develop the project to be more than 3axis such as 5axis

Chapter 2

Hardware Construction of the Machine

This chapter will discuss the main components of the project, types of motors used, their theory and equations.

2.1 Basic Construction of Stepper Motor

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.

2.1.1 Stepper Motor Advantages and Disadvantages

Advantages

1. The rotation angle of the motor is proportional to the input pulse.
2. The motor has full torque at standstill (if the windings are energized)
3. Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 – 5% of a step and this error is non cumulative from one step to the next.
4. Excellent response to starting/ stopping/reversing.
5. Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.
6. The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.
7. It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.
8. A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

1. Resonances can occur if not properly controlled.
2. Not easy to operate at extremely high speeds.

2.1.2 Open Loop Operation

One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system. Open loop control means no feedback information about position is needed. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. Your position is known simply by keeping track of the input step pulses.

2.1.3 Stepper Motor Types

There are three basic stepper motor types. They are:

- Variable-reluctance
- Permanent-magnet
- Hybrid

2.1.3.1 Variable-reluctance (VR)

This type of stepper motor has been around for a long time. It is probably the easiest to understand from a structural point of view. Figure 1 shows a cross section of a typical V.R. stepper motor. This type of motor consists of a soft iron multi-toothed rotor and a wound stator. When the stator windings are energized with DC current the poles become magnetized. Rotation occurs when the rotor teeth are attracted to the energized stator poles.

2.1.3.2 Permanent Magnet (PM)

Often referred to as a "tin can" or "canstock" motor the permanent magnet step motor is a low cost and low resolution type motor with typical step angles of 7.5 to 15. (48 – 24 steps/revolution) PM motors as the Figure 2.1.

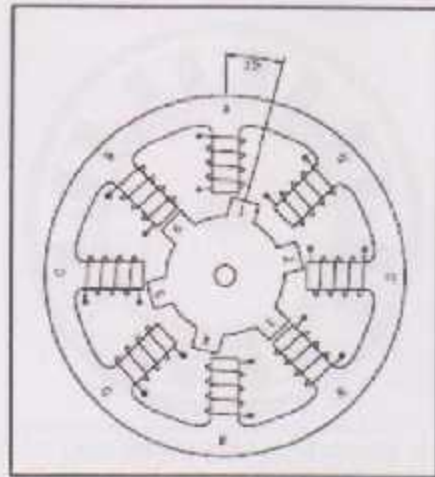


Figure 2.0.1 Cross-section of a variable reluctance (VR) motor.

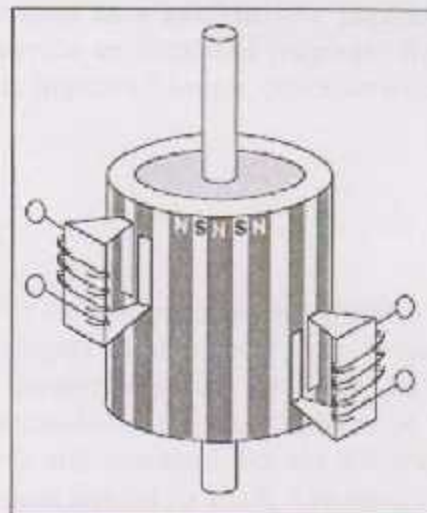


Figure 2.0.2 Principle of a PM or tin-can stepper motor.

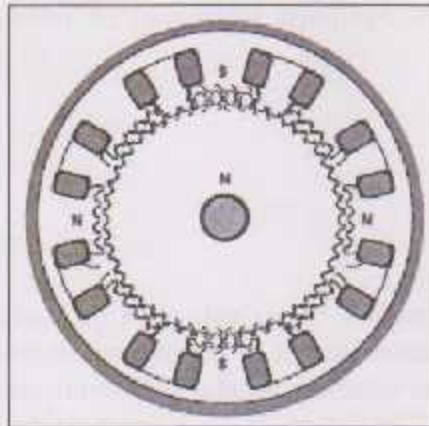


Figure 2.0.3 Cross-section of a hybrid stepper motor

name implies have permanent magnets added to the motor structure. The rotor no longer has teeth as with the VR motor. Instead the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide an increased magnetic flux intensity and because of this the PM motor exhibits improved torque characteristics when compared with the VR type.

2.1.3.3 Hybrid (HB)

The hybrid stepper motor is more expensive than the PM stepper motor but provides better performance with respect to step resolution, torque and speed. Typical step angles for the HB stepper motor range from 3.6 to 0.9 (100 – 400 steps per revolution). The hybrid stepper motor combines the best features of both the PM and VR type stepper motors. The rotor is multi-toothed like the VR motor and contains an axially magnetized concentric magnet around its shaft. The teeth on the rotor provide an even better path which helps guide the magnetic flux to preferred locations in the air gap. This further increases the detent, holding and dynamic torque characteristics of the motor when compared with both the VR and PM types.

The two most commonly used types of stepper motors are the permanent magnet and the hybrid types. If a designer is not sure which type will best fit his applications requirements he should first evaluate the PM type as it is normally several times less expensive. If not then the hybrid motor may be the right choice.

There also exist some special stepper motor designs. One is the disc magnet motor. Here the rotor is designed as a disc with rare earth magnets, See fig.2.5, This motor type has some advantages such as very low inertia and a optimized magnetic flow

path with no coupling between the two stator windings. These qualities are essential in some applications.

2.1.4 Size and Power

In addition to being classified by their step angle stepper motors are also classified according to frame sizes which correspond to the diameter of the body of the motor. For instance a size 11 stepper motor has a body diameter of approximately 1.1 inches. Likewise a size 23 stepper motor has a body diameter of 2.3 inches (58 mm), etc. The body length may however, vary from motor to motor within the same frame size classification. As a general rule the available torque output from a motor of a particular frame size will increase with increased body length. Power levels for IC-driven stepper motors typically range from below a watt for very small motors up to 10 – 20 watts for larger motors. The maximum power dissipation level or thermal limits of the motor are seldom clearly stated in the motor manufacturer's data. To determine this we must apply the relationship $PE = V \times EI$. For example, a size 23 step motor may be rated at 6V and 1A per phase. Therefore, with two phases energized the motor has a rated power dissipation of 12 watts. It is normal practice to rate a stepper motor at the power dissipation level where the motor case rises 65°C above the ambient in still air. Therefore, if the motor can be mounted to a heat sink it is often possible to increase the allowable power dissipation level. This is important as the motor is designed to be and should be used at its maximum power dissipation, to be efficient from a size/output power/cost point of view.

2.1.5 When to Use a Stepper Motor

A stepper motor can be a good choice whenever controlled movement is required. They can be used to advantage in applications where you need to control rotation angle, speed, position and synchronism. Because of the inherent advantages listed previously, stepper motors have found their place in many different applications. Some of these include printers, plotters, high-end office equipment, hard disk drives, medical equipment, fax machines, automotive and many more.

2.1.6 The Rotating Magnetic Field

When a phase winding of a stepper motor is energized with current a magnetic flux is developed in the stator. The direction of this flux is determined by the "Right Hand Rule" which states: "If the coil is grasped in the right hand with the fingers pointing in the direction of the current in the winding (the thumb is extended at a 90 angle to the fingers), then the thumb will point in the direction of the magnetic field."

Figure 2.5 shows the magnetic flux path developed when phase B is energized with winding current in the direction shown. The rotor then aligns itself so that the flux opposition is minimized. In this case the motor would rotate clockwise so that its south pole aligns with the north pole of the stator B at position 2 and its north pole aligns with the south pole of stator B at position 6. To get the motor to rotate we can now see that we must provide a sequence of energizing the stator windings in such a fashion that provides a rotating magnetic flux field which the rotor follows due to magnetic attraction.

2.1.7 Torque Generation

The torque produced by a stepper motor depends on several factors.

- The step rate
- The drive current in the windings
- The drive design or type

In a stepper motor a torque is developed when the magnetic fluxes of the rotor and stator are displaced from each other. The stator is made up of a high permeability magnetic material.

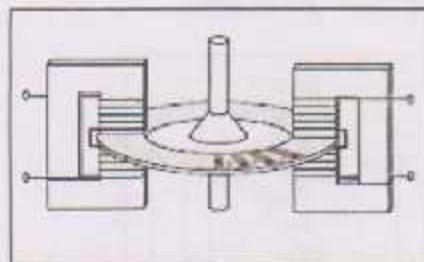


Figure 2.0.4 Principle of a disc magnet motor.

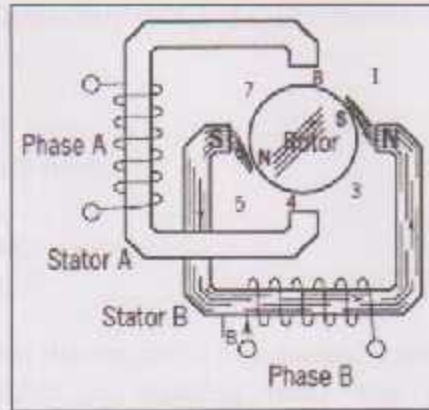


Figure 2.0.5 Magnetic flux path through a

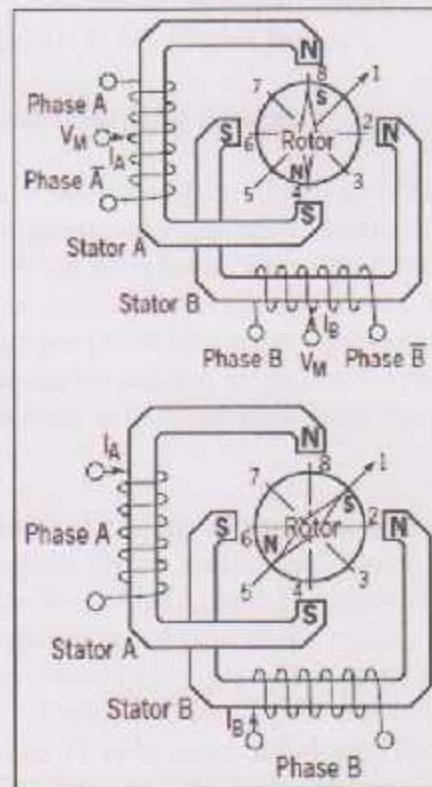


Figure 2.0.6 Unipolar and bipolar wound

The presence of this high permeability material causes the magnetic flux to be confined for the most part to the paths defined by the stator structure in the same fashion that currents are confined to the conductors of an electronic circuit. This serves to concentrate the flux at the stator poles. The torque output produced by the motor is proportional to the intensity of the magnetic flux generated when the winding

is energized. The basic relationship which defines the intensity of the magnetic flux is defined by:

$H = (N \times I) / L$ where:

N = The number of winding turns

i = current

H = Magnetic field intensity

l = Magnetic flux path length

This relationship shows that the magnetic flux intensity and consequently the torque is proportional to the number of winding turns and the current and inversely proportional to the length of the magnetic flux path. From this basic relationship one can see that the same frame size stepper motor could have very different torque output capabilities simply by changing the winding parameters. More detailed information on how the winding parameters affect the output capability of the motor can be found in the application note entitled "Drive Circuit Basics".

2.1.8 Phases, Poles and Stepping Angles

Usually stepper motors have two phases, but three- and five-phase motors also exist. A bipolar motor with two phases has one winding/phase and a uni-polar motor has one winding, with a center tap per phase. Sometimes the uni-polar stepper motor is referred to as a "four-phase motor", even though it only has two phases. Motors that have two separate windings per phase also exist—these can be driven in either bipolar or uni-polar mode. A pole can be defined as one of the regions in a magnetized body where the magnetic flux density is concentrated. Both the rotor and the stator of a step motor have poles.

Figure 2.2 contains a simplified picture of a two-phase stepper motor having 2 poles (or 1 pole pairs) for each phase on the stator, and 2 poles (one pole pair) on the rotor. In reality several more poles are added to both the rotor and stator structure in order to increase the number of steps per revolution of the motor, or in other words to provide a smaller basic (full step) stepping angle. The permanent magnet stepper motor contains an equal number of rotor and stator pole pairs. Typically the PM motor has 12 pole pairs. The stator has 12 pole pairs per phase. The hybrid type stepper motor has a rotor with teeth. The rotor is split into two parts, separated by a permanent magnet—making half of the teeth south poles and half north poles. The number of pole pairs is equal to the number of teeth on one of the rotor halves. The stator of a hybrid motor also has teeth to build up a higher number of equivalent poles (smaller pole pitch, number of equivalent poles = $360/\text{teeth pitch}$) compared to the main poles, on which the winding coils are wound. Usually 4 main poles are used for 3.6 hybrids and 8 for 1.8- and 0.9-degree types.

It is the relationship between the number of rotor poles and the equivalent stator poles, and the number of phases that determines the full-step angle of a stepper motor.

$$\text{Step angle} = 360 / (N_{ph} \times Ph) = 360 / N$$

N_{ph} = Number of equivalent poles per phase = Number of rotor poles

Ph = Number of phases

N = Total number of poles for all phases together

If the rotor and stator tooth pitch is unequal, a more-complicated relationship exists.

2.1.9 Stepping Modes

The following are the most common drive modes.

- Wave Drive (1 phase on)
- Full Step Drive (2 phases on)
- Half Step Drive (1 & 2 phases on)
- Microstepping (Continuously varying motor currents)

For the following discussions please refer to the figure 6.

In Wave Drive only one winding is energized at any given time. The stator is energized according to the sequence (A → B → A' → B') and the rotor steps from position (8 → 2 → 4 → 6). For unipolar and bipolar wound motors with the same winding parameters this excitation mode would result in the same mechanical position. The disadvantage of this drive mode is that in the unipolar wound motor you are only using 25% and in the bipolar motor only 50% of the total motor winding at any given time. This means that you are not getting the maximum torque output from the motor

Phase	Wave Drive				Normal full step				Half-step drive								
	1	2	3	4	1	2	3	4	1	2	3	4	5	6	7	8	
A
B							
A'						
B'			

Table 2.1 Excitation sequences for different drive modes

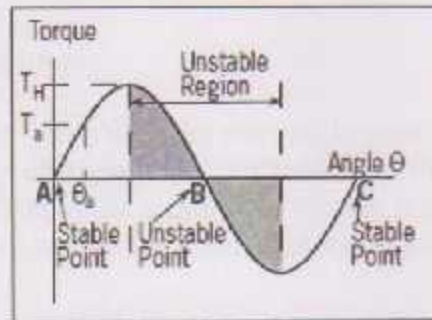


Figure 2.0.7 Torque vs. rotor angular position.

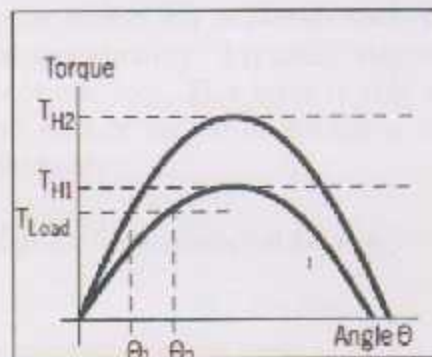


Figure 2.0.8 Torque vs. rotor angle position at different holding torque.

In Full Step Drive you are energizing two phases at any given time. The stator is energized according to the sequence $AB \rightarrow A'B \rightarrow (AB)' \rightarrow AB'$ and the rotor steps from position $1 \rightarrow 3 \rightarrow 5 \rightarrow 7$. Full step mode results in the same angular movement as 1 phase on drive but the mechanical position is offset by one half of a full step. The torque output of the unipolar wound motor is lower than the bipolar motor (for motors with the same winding parameters) since the unipolar motor uses only 50% of the available winding while the bipolar motor uses the entire winding. Half Step Drive combines both wave and full step (1&2 phases on) drive modes. Every second step only one phase is energized and during the other steps one phase on each stator.

The stator is energized according to the sequence $AB \rightarrow B \rightarrow A'B \rightarrow A' \rightarrow (AB)' \rightarrow B' \rightarrow AB' \rightarrow A$ and the rotor steps from position $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5 \rightarrow 6 \rightarrow 7 \rightarrow 8$. This results in angular movements that are half of those in 1- or 2-phases-on drive modes. Half stepping can reduce a phenomena referred to as resonance which can be experienced in 1- or 2- phases-on drive modes. The displacement angle is determined by the following relationship:

$X = (Z / 2\pi) X \sin(T_a / T_h)$ where:
 $Z =$ rotor tooth pitch

Ta – Load torque

Th – Motors rated holding torque

X – Displacement angle.

Therefore if you have a problem with the step angle error of the loaded motor at rest you can improve this by changing the “stiffness” of the motor. This is done by increasing the holding torque of the motor. We can see this effect shown in the figure 2.5. Increasing the holding torque for a constant load causes a shift in the lag angle from Q2 to Q1.

2.1.10 Step Angle Accuracy

One reason why the stepper motor has achieved such popularity as a positioning device is its accuracy and repeatability. Typically stepper motors will have a step angle accuracy of 3 – 5% of one step. This error is also noncumulative from step to step. The accuracy of the stepper motor is mainly a function of the mechanical precision of its parts and assembly.

Figure 2.9 shows a typical plot of the positional accuracy of a stepper motor.

Step Position Error

The maximum positive or negative position error caused when the motor has rotated one step from the previous holding position. Step position error = measured step angle - theoretical angle

Positional Error

The motor is stepped N times from an initial position ($N = 360/\text{step angle}$) and the angle from the initial position is measured at each step position. If the angle from the initial position to the N-step position is Φ_N and the error is $\Delta\Phi_N$ where:

$$\Delta\Phi_N = \Phi_N - (\text{step angle}) \times N.$$

The positional error is the difference of the maximum and minimum but is usually expressed with a \pm sign. That is:

$$\text{positional error} = \pm 1/2(\Delta\Phi_{\text{Max}} - \Delta\Phi_{\text{Min}})$$

Hysteresis Positional Error

The values obtained from the measurement of positional errors in both directions.

The excitation sequences for the above drive modes are summarized in Table 1. In Micro stepping Drive the currents in the windings are continuously varying to be able to break up one full step into many smaller discrete steps. More information on micro stepping can be found in the micro stepping chapter.

2.1.11 Torque vs, Angle Characteristics

The torque vs angle characteristics of a stepper motor are the relationship between the displacement of the rotor and the torque which applied to the rotor shaft when the stepper motor is energized at its rated voltage. An ideal stepper motor has a sinusoidal torque vs displacement characteristic as shown in figure 8.

Positions A and C represent stable equilibrium points when no external force or load is applied to the rotor shaft. When you apply an external force T_a to the motor shaft you in essence create an angular displacement, a . This angular displacement, a , is referred to as a lead or lag angle depending on whether the motor is actively accelerating or decelerating. When the rotor stops with an applied load it will come to rest at the position defined by this displacement angle. The motor develops a torque, T_m , in opposition to the applied external force in order to balance the load. As the load is increased the displacement angle also increases until it reaches the maximum holding torque, T_h , of the motor. Once T_h is exceeded the motor enters an unstable region. In this region a torque in the opposite direction is created and the rotor jumps over the unstable point to the next stable point.

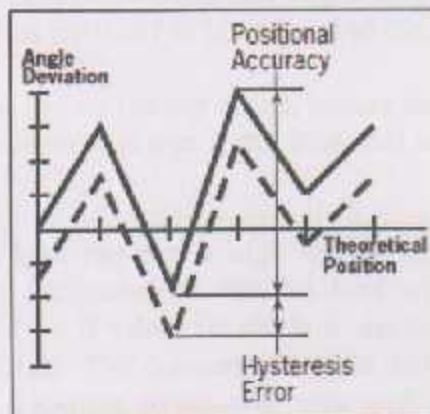


Figure 2.0.9 Positional accuracy of a stepper motor.

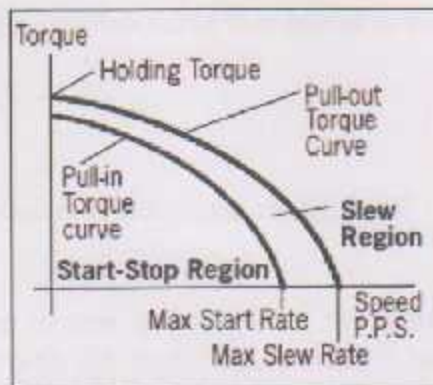


Figure 2.0.10 Torque vs. speed characteristics of a stepper motor.

2.1.12 Mechanical Parameters, Load, Friction, Inertia

The performance of a stepper motor system (driver and motor) is also highly dependent on the mechanical parameters of the load. The load is defined as what the motor drives. It is typically frictional, inertial or a combination of the two. Friction is the resistance to motion due to the unevenness of surfaces which rub together. Friction is constant with velocity. A minimum torque level is required throughout the step in order to overcome this friction (at least equal to the friction).

Increasing a frictional load lowers the top speed, lowers the acceleration and increases the positional error. The converse is true if the frictional load is lowered. Inertia is the resistance to changes

in speed. A high inertial load requires a high inertial starting torque and the same would apply for braking. Increasing an inertial load will increase speed stability, increase the amount of time it takes to reach a desired speed and decrease the maximum self start pulse rate. The converse is again true if the inertia is decreased. The rotor oscillations of a stepper motor will vary with the amount of friction and inertia load. Because of this relationship unwanted rotor oscillations can be reduced by mechanical damping means however it is more often simpler to reduce these unwanted oscillations by electrical damping methods such as switch from full step drive to half step drive.

2.1.13 Torque vs, Speed Characteristics

The torque vs speed characteristics are the key to selecting the right motor and drive method for a specific application. These characteristics are dependent upon (change with) the motor, excitation mode and type of driver or drive method. A typical "speed - torque curve" is shown in figure 9.

To get a better understanding of this curve it is useful to define the different aspect of this curve.

Holding torque

The maximum torque produced by the motor at standstill.

Pull-In Curve

The pull-in curve defines a area refered to as the start stop region. This is the maximum frequency at which the motor can start/stop instantaneously, with a load applied, without loss of synchronism.

Maximum Start Rate

The maximum starting step frequency with no load applied.

Pull-Out Curve

The pull-out curve defines an area refered to as the slew region. It defines the maximum frequency at which the motor can operate without losing synchronism.

Since this region is outside the pull-in area the motor must ramped (accelerated or decelerated) into this region.

Maximum Slew Rate

The maximum operating frequency of the motor with no load applied. The pull-in characteristics vary also depending on the load. The larger the load inertia the smaller the pull-in area. We can see from the shape of the curve that the step rate affects the torque output capability of stepper motor. The decreasing torque output as the speed increases is caused by the fact that at high speeds the inductance of the motor is the dominant circuit.

The shape of the speed – torque curve can change quite dramatically depending on the type of driver used. The bipolar chopper type drivers which Ericsson Components produces will maximum the speed – torque performance from a given motor. Most motor manufacturers provide these speeds - torque curves for their motors. It is important to understand what driver type or drive method the motor manufacturer used in developing their curves as the torque vs. speed characteristics of an given motor can vary significantly depending on the drive method used.

Stepper motors can often exhibit a phenomena referred to as resonance at certain step rates. This can be seen as a sudden loss or drop in torque at certain speeds which can result in missed steps or loss of synchronism. It occurs when the input step pulse rate coincides with the natural oscillation frequency of the rotor. Often there is a resonance

area around the 100 – 200 pps region and also one in the high step pulse rate region. The resonance phenomena of a stepper motor comes from its basic construction and therefore it is not possible to eliminate it completely. It is also dependent upon the load conditions. It can be reduced by driving the motor in half or micro stepping modes.

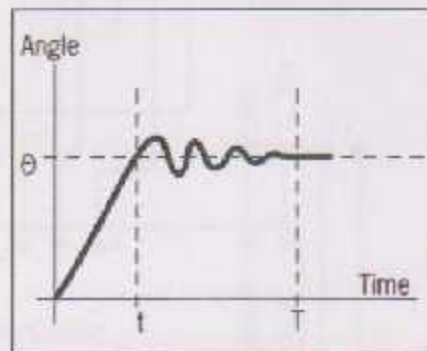


Figure 2.0.11 Single step response vs. time.

Single Step Response and Resonances

The single-step response characteristic of a stepper motor is shown in figure 11. When one step pulse is applied to a stepper motor the rotor behaves in a manner as defined by the above curve. The step time t is the time it takes the motor shaft to rotate one step angle once the first step pulse is applied.

This step time is highly dependent on the ratio of torque to inertia (load) as well as the type of driver used. Since the torque is a function of the displacement it follows that the acceleration will also be. Therefore, when moving in large step increments a high torque is developed and consequently a high acceleration. This can cause overshoots and ringing as shown. The settling time T is the time it takes these oscillations or ringing to cease. In certain applications this phenomena can be undesirable. It is possible to reduce or eliminate this behavior by micro stepping the stepper motor. For more information on micro stepping please consult the micro stepping note. Angle

2.2 Stepper Motor Driver and Controller

The Allegro 3967 driver chip that the EasyDriver is based off of is a bi-polar driver. This means it has a true H-bridge design internally, and sends current both ways through each of the two coils. You can use 4-wire, 6-wire or 8-wire stepper motors. The only kind you can't use is 5-wire stepper motors. (They need uni-polar drivers.)

Here's a little drawing on one way to hook up a six wire stepper motor to the EasyDriver.

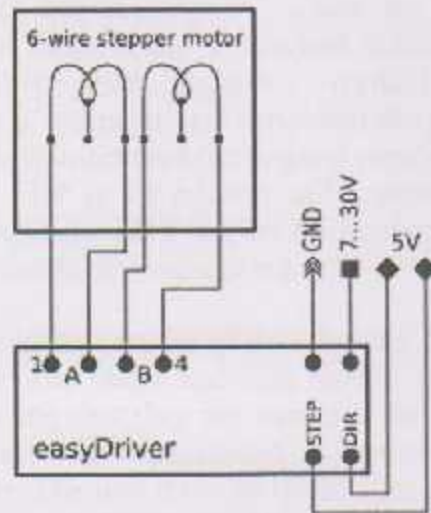


Figure 2.0.12 Single step response vs. time.

As we can see in figure 2.12 the pins of easy driver is being soldered and put into a breadboard, then the 4 pins (1,A,B,4) is soldered to wires of the motor in bipolar mode, then it is feeded with 12 DCV and a square wave is connected to the step pin

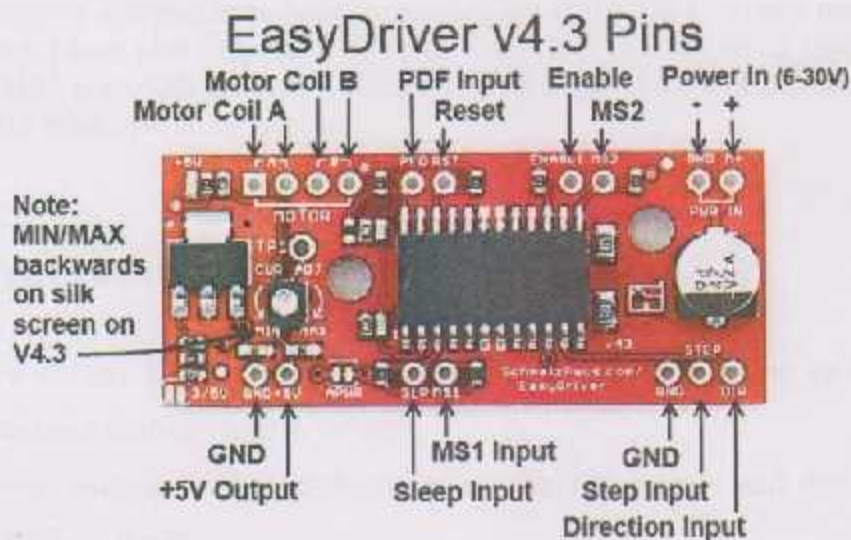


Figure 2.0.13 easy driver upper view

Data Transfer

The transferring of data between the PC where the desired image is designed is transferred by a parallel cable, using a standard called EPP/ECP (Enhanced Parallel Port/Enhanced Capability Port signaling method for bi-directional parallel communication between a computer and peripheral devices that offers the potential for much higher rates of data transfer than the original parallel signaling methods. EPP is for non-printer peripherals. ECP is for printers and scanners. EPP/ECP are part of IEEE Standard 1284, which also specifies support for current signaling methods so that both old and new peripherals can be accommodated.

The new standard specifies five modes of data transfer. Three of them support the older mono-directional modes. The fourth and fifth modes, EPP and ECP, are bi-directional signaling methods, meaning that they are designed for back-and-forth communication. Partly because these are being implemented in hardware, EPP and ECP will provide much faster data transfer. The first three methods offer an effective data transfer rate of 50 to 100 kilobytes per second. EPP and ECP offer the possibility of rates "in excess of 1 megabyte per second," according to Warp Nine, a chip manufacturer.

In order to get the maximum advantage of EPP/ECP, both operating system (or an I/O port controller, or both) and peripheral device must support the standard. Even printers that support ECP are limited by the mechanical aspects of printing. Nevertheless, even users of the compatibility modes of Standard 1284 are also expected to see some benefit in data transfer to and from peripherals.

Linux operating systems have built-in support for IEEE 1284 in their parallel plug and play feature. Linux also supports ECP in forward direction, assuming you have a printer and a parallel port with ECP. It is likely that other vendors will provide ECP or EPP software for other operating systems.

2.3 Types of signals

- Low voltage signals: voltages that is 5 VDC +/- that powers up the interfacing board and enables them to be used
- Power voltages: voltages that operates the DC motors and the servo ones in addition to the PC.

- Data signals: signals that is transferred in the PC sector to the interfacing board sector in order to process it and convert it to the controlling signals and vice versa.
- Control signals: the pulse width modulated signals generated to the servo motors and the encoder signals that indicated the motors position.

2.4 Mechanical and Pneumatic Components

There are two types of mechanical motioning for the motors on the axes, the first type is the linear bearing which slides on a rail and is considered as a low friction item. And lead screw is considered for z-axis which hold the mountings of spindle and its axis.

2.4.1 Lead screw and Homing Bearings

A lead screw is a screw specialized for the purpose of translating rotational to linear motion. The mechanical advantage of a lead screw is determined by the screw pitch or lead.

A lead screw nut and screw mate with rubbing surfaces, and consequently they have a relatively high friction compared to mechanical parts which mate with rolling surfaces and bearings. Their efficiency is typically only between 25 and 70%, with higher pitch screws tending to be more efficient. A higher performing, and more expensive, alternative is the ball screw. Figure 2.6 shows the screw lead of an axis which is driven by a pulley.

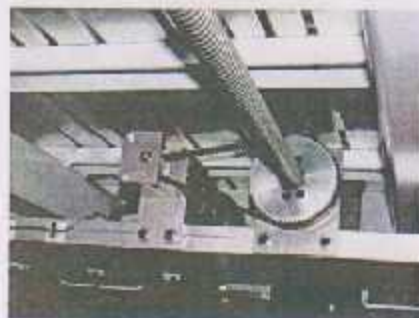


Figure 2.D.14 lead screw

The high internal friction means that lead screw systems are not usually capable of continuous operation at high speed, as they will overheat. Due to inherently high friction, the typical screw is self-locking (ie. when stopped, a linear force on the nut will not apply a torque to the screw) and are often used in applications where back driving is unacceptable, like holding vertical loads or in hand cranked machine tools.

Lead screws are typically used well-greased, but, with an appropriate nut, it may be run dry with somewhat higher friction. There is often a choice of nuts, and manufacturers will specify screw and nut combinations as a set, some other kinds are supporting the leadscrew with its bearing rail for smashing out the friction losses from movements.

2.4.2 Spindle Head Motor

The Engraving Component of the Machine Selected here is the Air compressed Type with electrical signal control. Its rotating speed due to its specifications is more than 54000 RPM, its weight is 0.33 Kg and its length is collet size is 3mm. It holds an Air Pressure of 6 Bar, Figure 2.15 shows the general picture of the spindle motor. Where the supplying power of rotation is the compressed air at 6 Bar.

The electrical control component for this head motor is the electro-pneumatic valve as shown in figure 2.16, and the next figure 2.17 shows the equivalent electrical controlling circuit.



Figure 2.0.15 general picture of the head motor

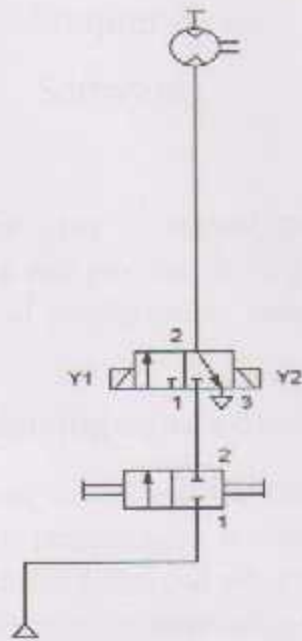


Figure 2.0.16 pneumatic diagram of the head motor

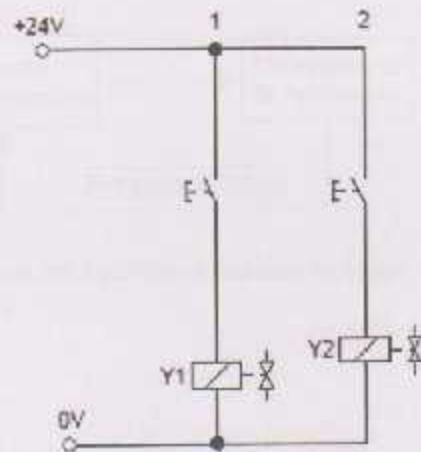


Figure 2.0.17 Electric equivalent circuit of controlling the head motor

And Here we proceed in the next Chapter to discuss the Software section of the machine that is used to design the desired reference prototype of the drawing being engraved by the machine.

Chapter 3

Software

3.1 Introduction

This chapter presents the software used to control the machine and organize its performance such as lathes working and position moving by the stepper motors along axes. Where it will contain units of configuration, running example and integrating settings between them.

3.2 PC and reference driving signals block

the PC computer as the programming device and the software is the program that the code is being put in and when all the programming is done the G-code being inserted is transferred to an interpreter to check for errors and when there are no errors the coding language is translated by the interpreter to the interfacing circuit as data signals through the parallel port. The description of the software operation in the system simply could be shown in fig 3.1

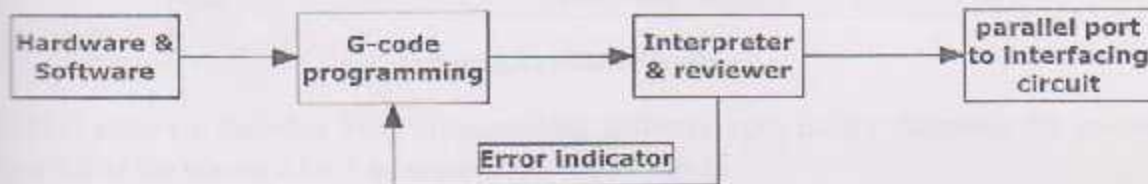


Figure 3.0.1 software processing for image

3.3 The Software

EMC (the Enhanced Machine Control) is a software system for computer control of machine

tools such as milling machines and lathes, where it is a free software with open source code (GPL – General Public License), where it has multiple graphical user interfaces that increases the feasibility of using it, supporting of G-code interpreting using RS-274 machine tool programming language. In addition to that there is a realtime motion planning system with look ahead which works as a simulator for the running spindle on

the piece of work as shown in fig 3.2, here we saw the cone as a spindle working on drawing a text example

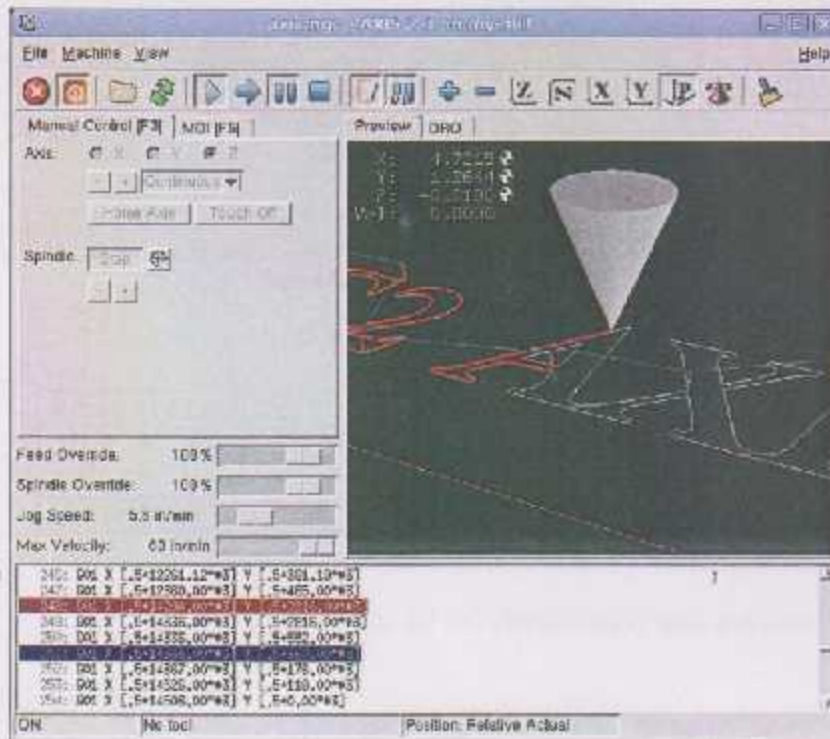


Figure 3.0.2 software interface

This software includes PLC programming software with ladder diagrams for overall control of the machine such as sensors and motor drives.

Starting configuration of your PC to be able to hold this software operations especially its suitability for software step pulse generation using Latency Test, Latency is how long it takes the PC to stop what it is doing and respond to an external request. In our case, the request is the periodic "heartbeat" that serves as a timing reference for the step pulses. The lower the latency, the faster you can run the heartbeat, and the faster and smoother the step pulses will be. Fig 3-2 shows a window of the latency test to a PC where the important numbers are the "max jitter" which decides the compatibility of running requirements according to table 3-1

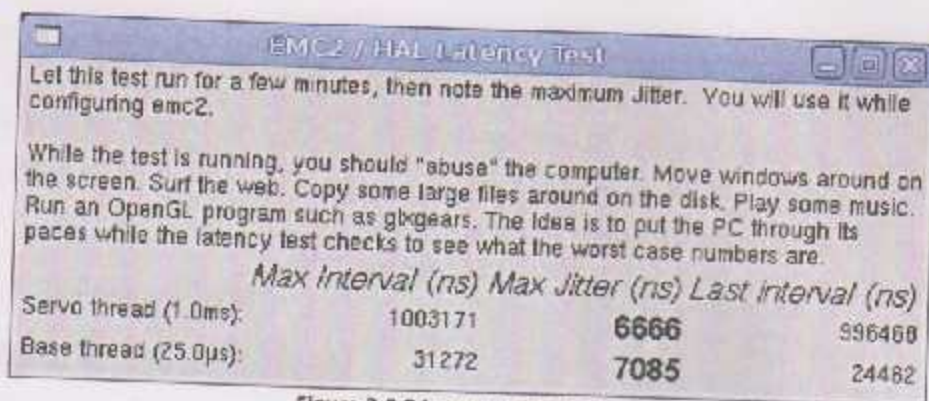


Figure 3.0.3 Latency test window

Range of Max Jitter (MJ)	Evaluation
MJ < 15 – 20 µs	Very good predicted results
MJ > 30 – 50 µs	Good but having errors in stepping
MJ > 100 µs	Not good for stepping
MJ > 1 ms	Not compatible with software

Table 3-1 Latency test results for PC compatibility with software

3.4 Configuration

In order to run the software with compatible hardware components we need to enter a specifically parameters of these components to make the suitable outputs of the software coming right for the machine. These parameters include the pulley ratio, lead screw pitch according to the length scale, maximum velocity for an axis in units per second. Homing location if it is other than the default positions (0,0,0), time and distance to accelerate a motor to max speed. Pulse rate at maximum speed and testing the axis to show how will the axis work after entering the related parameters.

Meanwhile, spindle configuration needs parameters such as pwm rate (carrier frequency of the PWM signal to the spindle) which is useful for generating an analog control voltage. Determining its calibration for speeds 0 and 1000 rpm to choose switching the pwm on or off for these cases. After the configuration is finished we could launch the EMC software.

3.5 EMC (Enhanced Machine Controller)

After configuration has been set to ensure the performance of the PC with the software, we can check the performance of the software with the hardware attached to it as servo motors according to fig 3-3, where the software has 4 main components: a motion

controller, a discrete I/O controller, a task executor for coordination and graphical user interfaces. In addition to that it has a layer called HAL (Hardware Abstraction Layer) which allows configuration of EMC without the need of recompiling.

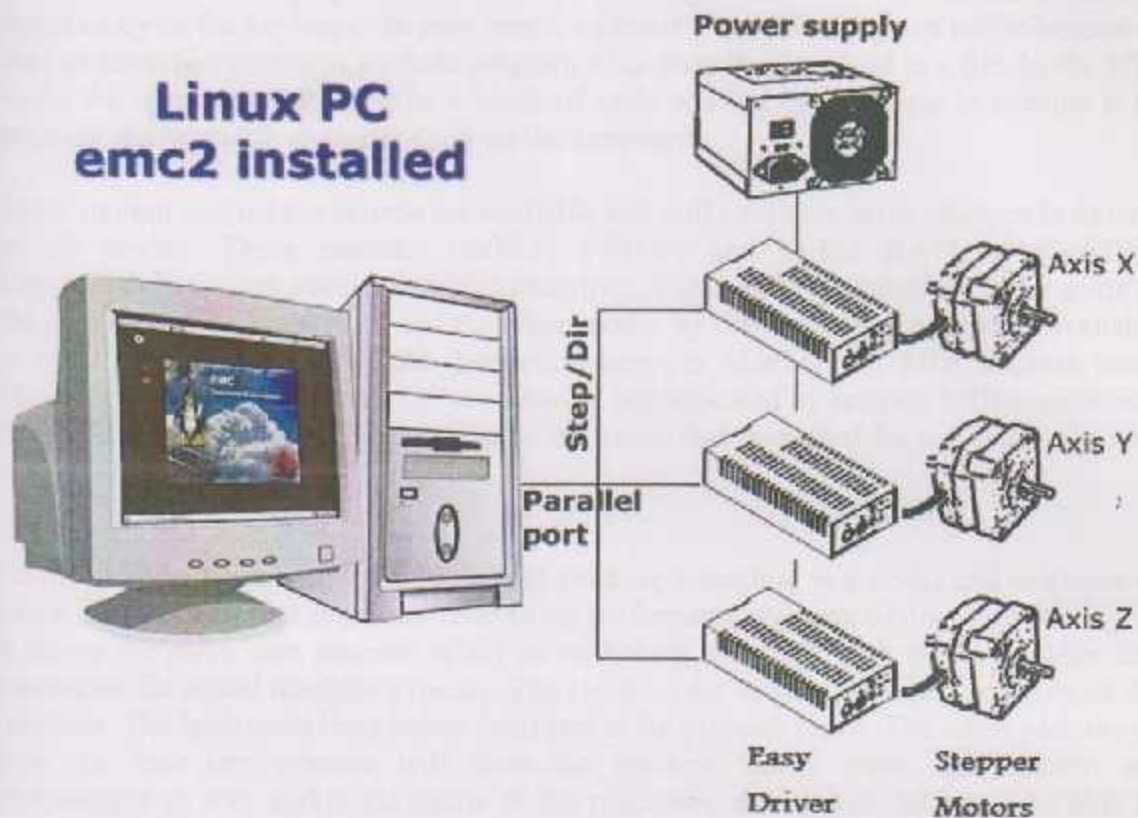


Figure 3.0.4 stepper system with EMC

Modes of operation

When an EMC is running, there are three different major modes used for inputting commands.

These are Manual, Auto, and MDI (Manual Data Input). Changing from one mode to another makes a big difference in the way that the EMC2 behaves. There are specific things that can be done in one mode that cannot be done in another. An operator can home an axis in manual mode but not in auto or MDI modes. An operator can cause the machine to execute a whole file full of G-codes in the auto mode but not in manual or MDI.

In manual mode, each command is entered separately. In human terms a manual command might be "turn on coolant" or "jog X at 25 inches per minute". These are roughly equivalent to flipping a switch or turning the hand wheel for an axis. These commands are normally handled on one of the graphical interfaces by pressing a button with the mouse or holding down a key on the keyboard. In auto mode, a similar button or key press might be used to load or start the running of a whole program of G-code that is stored in a file. In the MDI mode the operator might type in a block of code and tell the machine to execute it by pressing the <return> or <enter> key on the keyboard.

Some motion control commands are available and will cause the same changes in motion in all modes. These include ABORT, ESTOP, and FEED RATE OVERRIDE. Commands like these should be self explanatory. The AXIS user interface hides some of the distinctions between Auto and the other modes by making Auto-commands available at most times. It also blurs the distinction between Manual and MDI because some Manual commands like Touch Off are actually implemented by sending MDI commands. It does this by automatically changing to the mode that is needed for the action the user has requested.

Controlling the planner to follow a path of working according to g-codes and existence of naïve cam detector that improves contouring performance by simplifying the path. Fig 3-4 shows the naïve cam detector effect on enhancing a contour path where the blue line represents the actual machine velocity. The red lines are the acceleration capability of the machine. The horizontal lines below each plot is the planned move. The upper plot shows how the trajectory planner will slow the machine down when short moves are encountered to stay within the limits of the machines acceleration setting to be able to come to an exact stop at the end of the next move. The bottom plot shows the effect of the Naive Cam Detector to combine the moves and do a better job of keeping the velocity as planned.

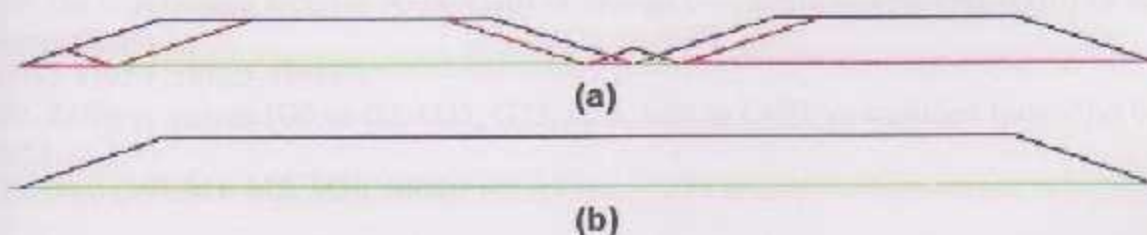


Figure 3.0.5 a-the path before working of naïve cam detector

b- the path after naïve cam detector

A trajectory planning is applied to this system using the G-codes, However the code program can never be fully obeyed. For example if we specify a single line as follows:

G1 X1 F10 (G1 is linear move, X1 is the destination, F10 is the speed)

In reality, the whole move can't be made at F10, since the machine must accelerate from a stop, move toward X=1, and then decelerate to stop again. Sometimes part of the move is done at F10, but for many moves, especially short ones, the specified feed rate is never reached at all. Having short moves in your G Code can cause your machine to slow down and speed up for the longer moves if the "naive cam detector" is not employed with G64 Pn

3.6 Execution of codes

As any program there is an order of executing lines coded by the user we could see the following points executed simultaneously:

1. Comment (including message)
2. Set feed rate mode (G93, G94).
3. Set feed rate (F).
4. Set spindle speed (S).
5. Select tool (T).
6. Change tool (M6).
7. Spindle on or off (M3, M4, M5).
8. Coolant on or off (M7, M8, M9).
9. Enable or disable overrides (M48, M49).
10. Dwell (G4).
11. Set active plane (G17, G18, G19).
12. Set length units (G20, G21).
13. Cutter radius compensation on or off (G40, G41, G42)
14. Cutter length compensation on or off (G43, G49)
15. Coordinate system selection (G54, G55, G56, G57, G58, G59, G59.1, G59.2, G59.3).
16. Set path control mode (G61, G61.1, G64)
17. Set distance mode (G90, G91).
18. Set retract mode (G98, G99).
19. Go to reference location (G28, G30) or change coordinate system data (G10) or set axis offsets (G92, G92.1, G92.2, G94).
20. Perform motion (G0 to G3, G33, G73, G76, G80 to G89), as modified (possibly) by G53.
21. Stop (M0, M1, M2, M30, M60).

Baring in mind the options of coding them depending on scaling in mms or inches and use 4 or 3 digits. And putting important modal settings at the top of the file, for example using the following command line "G17 G20 G40 G49 G54 G80 G90 G94 " which is translated to human definition to XY plane, inch mode, cancel diameter compensation,

cancel length offset, coordinate system 1, cancel motion, non-incremental motion, feed/minute mode.

M codes are used for stopping and spindle changing purposes depending on the desired image needed to be processed by the software.

And here we end this Chapter and prepare ourselves to know the overall operation of the machine in Chapter 4

Chapter 4

Design and construction

4.1 Block Diagram

The full system components are shown in figure 4.1 which was presented in previous chapters. A technological and modern plants uses software as designing tools, driving block to control the motion of the system and making its operation feasible. Protection elements is not only in the electronic boards, it will be also in the power circuit such as fuses, overloads before the motors, and emergency buttons that could be connected to the controller as it is within its features.

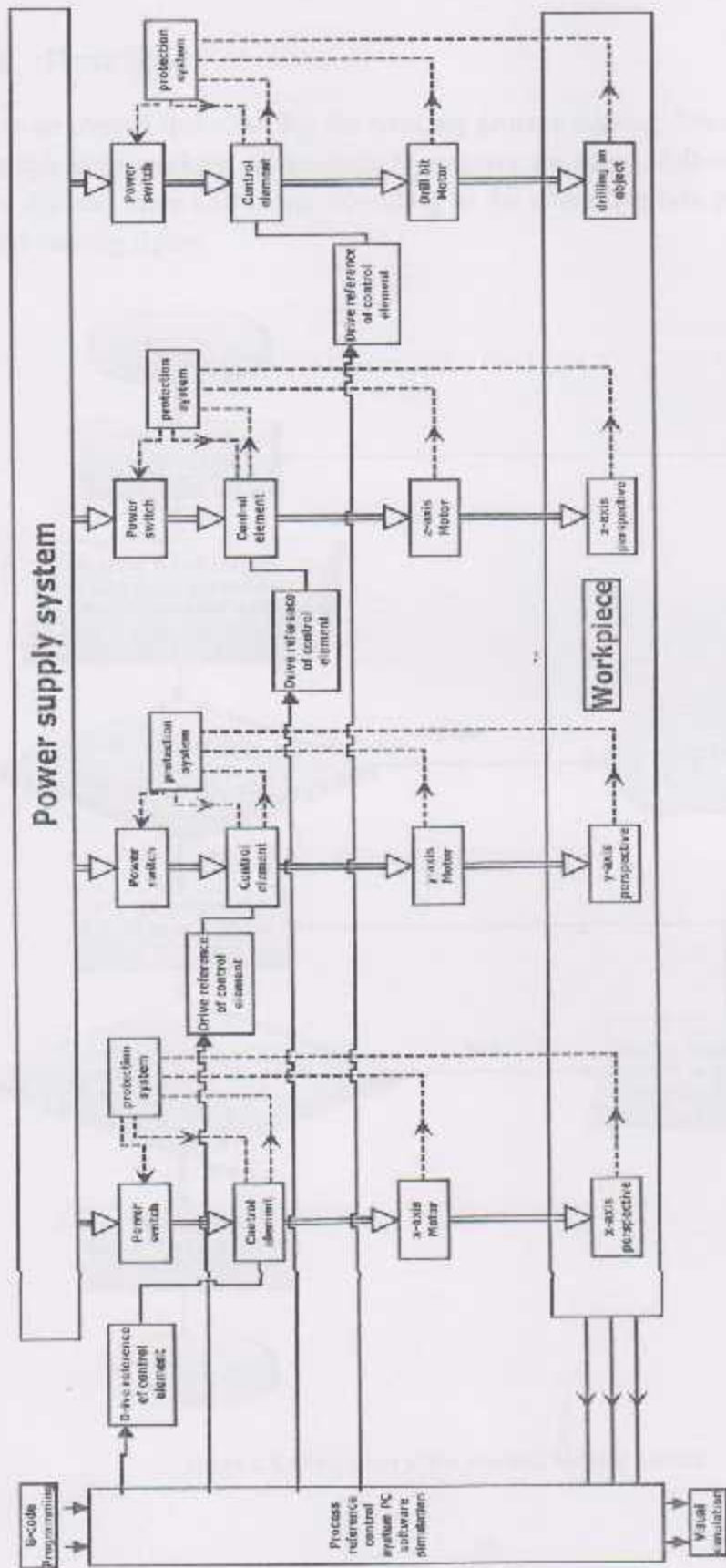


Figure 4.0.1 Overall block diagram

4.2 Flow Chart

This is an overall flowchart for the working process starting from using the PC to design the graph until working of machine to engrave on wood, following steps illustrated in figure 4.2 and there will be an extending to the engraving box process according to the desired carving figure.

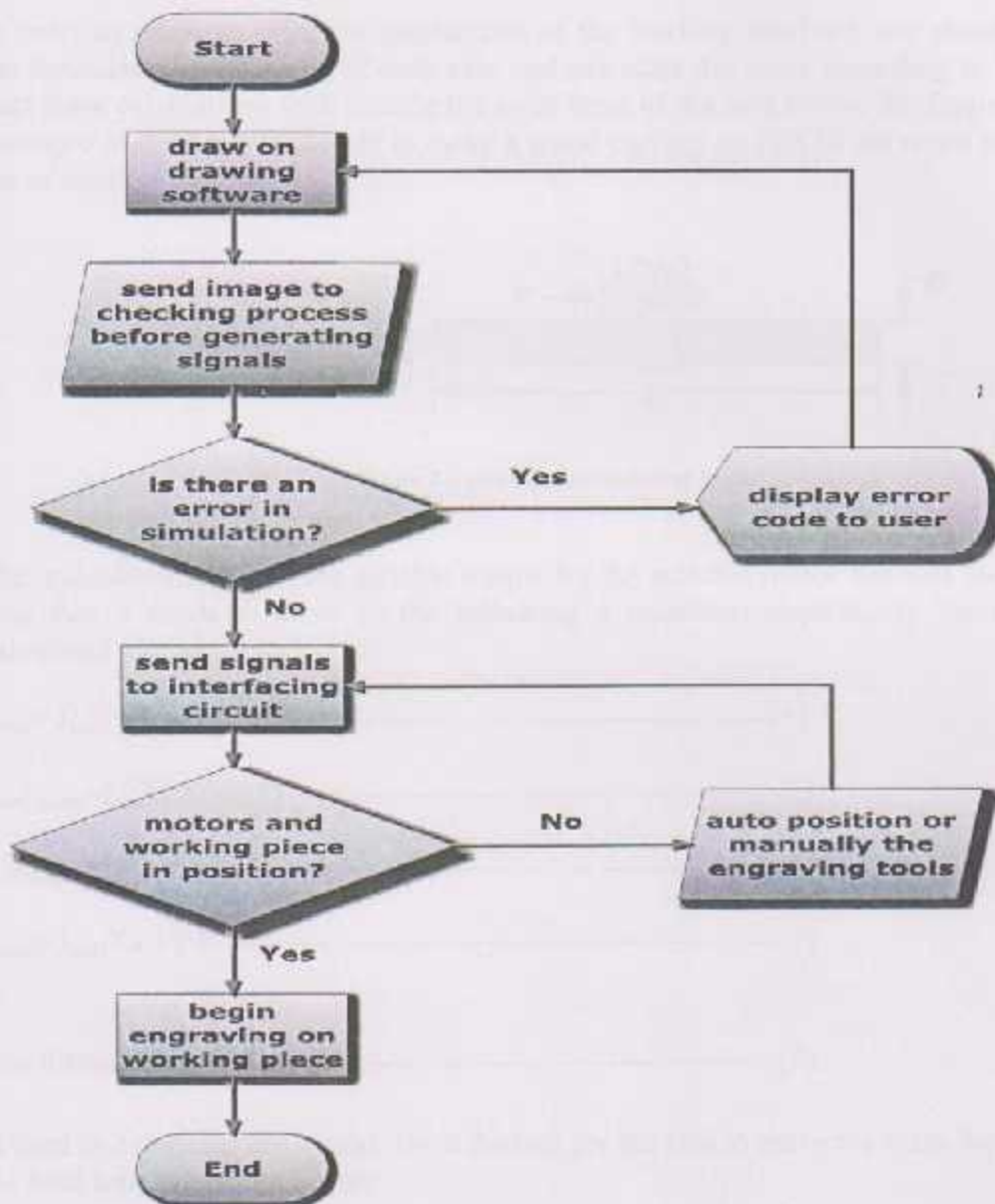


Figure 4.0.2 flow chart of the machine working process

As what occurred in the practical application of the motor and depending on the Common types of moving machines the machine is classified to have a moving table and a fixed z-axis mounted on the body of the machine. The following part is considering calculations to determine the load of each axis here.

4.3 Mathematical Calculation of Motors

In order to reach an effective mechanism of the working machine, one should consider the formulas of movement of each axis and calculate the loads according to it. We will start these calculations with finding the axial force of the lead screw, the figure 4.3 shows a sample of it where we decide to make a wood carving on 50X50 cm wood piece with 3 cm of depth.

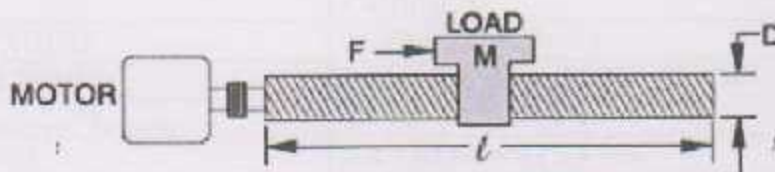


Figure 4.3 axis representation of forces

The calculations to find the suitable torque for the selected motor depends mainly on the load that it needs to drive so the following 4 equations sequentially leads us to the calculated torque.

$$J_{total} = J_{rotor} + J_{steel\ screw} + J_{reflected} \text{-----(1)}$$

$$J_{steel\ screw} = D^4 \times L \times (\pi/32) \text{-----(2)}$$

$$J_{reflected} = M \times L^2 \times 0.025 \text{-----(3)}$$

$$T_{total} = J_{total} \times \alpha + T_d \text{-----(4)}$$

$$\text{The formula } F = \frac{2\pi T}{L} \times \eta \text{-----(5)}$$

Is used to determine the overall force desired for the axis to move the mass depending on the total torque calculated here.

where

F = axial force in Nm

T = Torque in mNm

L = Lead screw length in meters

η = efficiency equals 0.3 for ACME lead screw

4.3.1 X-axis motor calculations

To find the needed torque for driving the existing load for each axis, the following table clarifies it mathematical step by step approach

Equation	Calculation
$J_{reflected} = MXL^2 \times 0.025$	$16 \times 0.5^2 \times 0.025 = 0.1$
$J_{steel\ screw} = D^4 XLX(\pi/32)$	$0.032^4 \times 0.5 \times (\pi/32) \times (7.83 \times 10^6) = 0.403 \text{ gm}^2$
$J_{total} = J_{rotor} + J_{steelscrew} + J_{reflected}$	$27.14 + 0.403 + 0.1$
$T_{total} = J_{total} \times \alpha + T_d$	$0.4 + 10.84 = 11.24 \text{ Nm}$

Where

$J_{reflected}$ is the reflected inertia of the load in g.m^2

M is load mass in Kg

D is diameter of screw in mm

4.3.2 Y-Axis motor calculations

Equation	Calculation
$J_{reflected} = MXL^2 \times 0.025$	$10 \times 0.5^2 \times 0.025 = 0.0625 \text{ kgm}^2$
$J_{steel\ screw} = D^4 XLX(\pi/32)$	$0.018^4 \times 0.5 \times (\pi/32) \times (7.83 \times 10^6) = 0.0403 \times 10^{-4} \text{ kgm}^2$
$J_{total} = J_{rotor} + J_{steelscrew} + J_{reflected}$	$12.43 + 0.0403 \times 10^{-4} + 0.0625 = 12.43 \times 10^{-4} \text{ kgm}^2$
$T_{total} = J_{total} \times \alpha + T_d$	$(12.43 \times 10^{-4} + 4.03 \times 10^{-4} + 0.0625) \times 5.76 = 6 \text{ Nm}$

4.4 Testing Results

To use the machine appropriately we followed the following steps in order to make the desired engraving on the machine in the following points:

- 1- Opening the EMC after calibrating it to the stepper and its rails along the axes.
- 2- The program convert the data (picture, scribe or drawing ... etc) converted to g-code.
- 3- The drilling head is starting with high speed
- 4- Motor move at x,y and z axes and draw the picture.

Notes:

The actual price of the machine appears in the following table according to the prices available in the local market

Item	Quantity	Cost/Qty (US\$)	Units price (US\$)
Steper motor	3	200	600
DC motor	1	150	150
Computer	1	150	150
Interfacing Board	1	400	400
Wiring and mountings	-	100	100
Lathe work	-	1000	1000
Total Price			2400

4.5 Conclusion

We conclude the following from this project:

The task was to find an industrial machine that solves the manual working problems in production such as time consuming and low accuracy, so the machine was found to solve these points. To build a machine that is compatible with modern industrial technologies as computerized systems and the demands of local market. The software program EMC2 combines between the electrical and mechanical parts of system. The result was that the stepper motors are well used in such machines and can handle the work in addition to producing pieces of wood that is being engraved and ready to be sold in quantities. Your opinion about results and verification of results accuracy The result was satisfying but limited to the range of the working pieces that is approximated to (16cmX32cm).

4.6 Recommendations

- 1- From what is remarked in this machine the availability of transferring the machine which is being considered as a low level of production machines. What would be more efficient is finding more technological parts to be used in spite of unavailability of such complex technology to be found locally.

- 2- In this kind of project there should be a mechanical engineer for development of the machine motion.
- 3- We recommend making a machine in bigger size for higher level of production such as doors or walls or artificial parts.
- 4- In the higher level production machines it is recommended to use motors with higher torque level, which is compatible to be operated by CNC softwares.

References

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- [3] Pico systems
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- [5] Enhanced machine controller (EMC2)
- [6] Techtarget

Appendices

Trapezoidal screws & Nuts – Engineering Data (SI Units)

A Thread Size (dia. X lead) (mm)	B Lead (mm/r ev.)	C Equivalent English Thread/Size (OD-TPI)	D Static Load Rating (Bronze + Nut) (kN)	E Operating Load Rating (Bronze Nut) (kN)	F Operating Load Rating (Plastic Nut) (kN)	G Minor Diameter I (mm)	H Drive Torque Ratio (Nm/k N)	I Forw ard Drive Effici ency	J Scre w Wei ght (kg/ m)
10 X 2	2.000	.394 - 12.700	11	3	2	7.040	1.020	31%	.48
12 X 3	3.000	.472 - 8.467	16	5	2	7.950	1.300	37%	.65
14 X 3	3.000	.551 - 8.467	20	7	3	9.930	1.450	33%	.94
16 X 3	3.000	.630 - 8.467	27	9	4	11.910	1.630	29%	1.26
16 X 4	4.000	.630 - 6.350	27	9	4	10.850	1.750	36%	1.18
18 X 4	4.000	.709 - 6.350	35	11	5	12.830	1.910	33%	1.55
20 X 4	4.000	.787 - 6.350	44	14	7	14.830	2.060	31%	1.95
24 X 5	5.000	.945 - 5.080	63	20	10	17.750	2.490	32%	2.78
28 X 5	5.000	1.102 - 5.080	85	27	14	21.740	2.790	28%	3.93
30 X 6	6.000	1.181 - 4.233	88	28	14	22.200	3.230	30%	4.36
32 X 6	6.000	1.260 - 4.233	114	35	17	24.180	3.230	30%	5.07
36 X 6	6.000	1.417 - 4.233	145	45	22	28.170	3.530	27%	6.59
40 X 7	7.000	1.575 - 3.629	175	55	27	31.090	3.990	28%	8.06
44 X 7	7.000	1.732 - 3.629	215	68	34	35.080	4.290	26%	9.96
48 X 8	8.000	1.890 - 3.175	255	80	40	38.020	4.720	27%	11.7
52 X 8	8.000	2.047 - 3.175	300	96	48	42.010	5.030	25%	14.0

AIR MICRO GRINDER FOR INDUSTRIAL USE	
Model	TG-3180
FREE SPEEDS	58000 RPM
COLLET SIZE	3 mm or 1.8"
NET WEIGHT	0.33 KGS
LENGTH	132 mm
AIR PRESSURE	90 PSI
Hose size	5 mm
Sound Pressure	80 dBA
Vibration	<2.5 m/S ²
Packing	20 pcs/1.25 cu.ft/G:15 kgs



Model 8263

2-Way Brass Diaphragm Valve

- Ideal for Control of Neutral Gases and Liquids
- Hot Water & Steam Valves Available
- Operates at Zero Pressure Differential
- High Flow Capacity
- Compact Design



Technical Data

Function: 2-Way Normally Closed

Ports (NPT)	Orifice	Cv	Operating Pressure Range (PSI)*
1/4"	3/8"	1.8	0 - 145 PSI (0 - 10 bar)
3/8"	3/8"	2.0	0 - 145 PSI (0 - 10 bar)
1/2"	3/8"	2.0	0 - 145 PSI (0 - 10 bar)

*0 - 87 PSI (0 - 6 bar): HNBR Seal

Temperature Rating

Ambient:

14°F to 140°F (-10°C to +60°C)

14°F to 122°F (-10°C to +50°C) - HNBR

Fluid:

14°F to 194°F (-10°C to +90°C) - Buna

14°F to 230°F (-10°C to +110°C) - EPDM, Fluorocarbon

14°F to 302°F (-10°C to +150°C) - HNBR

Power Rating: 12 Watt

Voltage:

24 VDC

24/50, 110/50, 120/60, 220/60, 230/50 Volt AC

Electrical Connector: DIN Style Plug with Removable Cable Plug Adapter

Body: Brass

Diaphragm:

Buna (Standard)

Fluorocarbon, EPDM, HNBR (Optional)

Other Wetted Parts: Brass, Polyamid 66

Coil: Class F, Molded, Continuous Duty, UL Recognized

Part Number Identification

A 8 - 8 2 6 3 - 0 5 | 0 7 - 0 1 - U - Voltage - Optional

VALVE SERIES

PORTS

ORIFICE

SEAL

SUFFIX

05 = 1/4" NPT

07 = 3/8" NPT

08 = 1/2" NPT

07 = 3/8"

01 = Buna

02 = Fluorocarbon

03 = EPDM

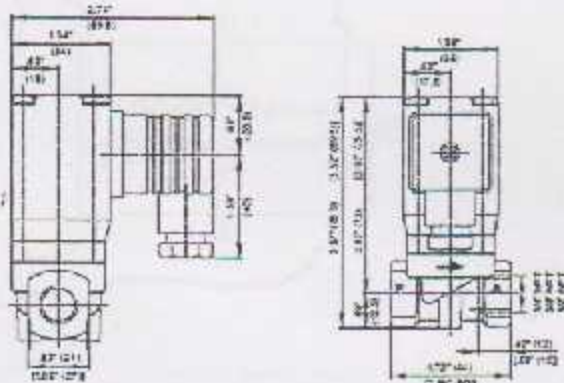
04 = HNBR (Steam)

00 = 1/2" NPT Corded

0L = 1/2" NPT Corded w/ 2" Lead Wires

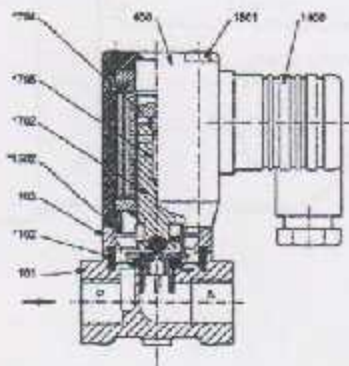
2" Lead Wires

Model 8263
 All Dimensions in Inches (mm)



Power Consumption

DC	AC	
	Inrush	Holding
12W	20VA	16VA



- 101 Valve body
- *102 Diaphragm
- 103 Spacer
- 400 Coil
- *702 Plunger
- *704 Guide pin
- *705 Pressure spring
- 1409 Electrical connector
- 1001 Oval head cap screw
- *1502 O-ring

* These individual parts form a complete working unit. When ordering spare parts please cite complete part number.

Wiring

