DESIGN AND BUILD AN AUTOMATIC PCB DRILLING MACHINE

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ABSTRACT

Creating holes on single or multilayer printed circuit boards (PCBs) is an important stage in electronic production. Holes of different sizes and at a large number of positions (up to thousands) must be drilled with high precision for manual or automatic insertion of various electronic devices and components. For this purpose, we have designed and built an automatic PCB drilling machine. The PCB pattern of the circuit schematic diagram is drawn on the monitor screen, with the help of a software such as Orcad. This pattern layout is printed out to make the PCB, and it's just from this layout the computer will control the drilling automatically. At a time the system can make holes on several boards stacked together. There are many foreign made PCB drilling machines of different quality that we could have imported, but because of their high price and, moreover, we wanted to build a robust machine with a large span (can accommodate boards up to 50 cm in width) for making holes, or making printed boards (board etching), and as a demonstrating CNC machine (by changing corresponding working head). The project has been completed and put in use (making small scale PCBs and teaching).

1. DESIGN IDEA

There are three kinds of holes on PCBs: Holes for device insertion, via holes and fringe holes for board fixing. Each hole has two parameters: Position and size (diameter). Hole quality is also important. Hole position consists of X-Y coordinates measured from monitor screen upper left corner. These parameters are used to position the drilling bit, whereas size parameter is used to choose bit size (usually 0.7mm, 0.8mm . . .). Hole data file supplied by the electronic software is for controlling the drilling machine.

The drill (comprising motor, chuck, and bit) is moved horizontally to X-Y coordinates of a hole, then moved down in Z direction to make the hole, then withdrawn and translated to another place.

The electro-mechanical system is responsible for the 3D motion to position the drill, and should be of real industry standard to guarantee the force, torque, precision, robustness . . . requirements. The idea was to choose stepper motors and linear axes for the electro-mechanical system. Servo motors are more appropriate but stepper motors are more convenient. Figure 1 is the general model of the drilling machine resulted from above ideas.

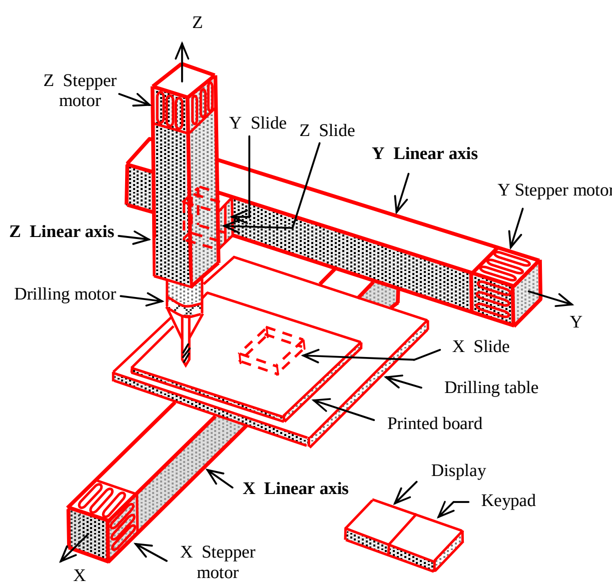

Fig.1 General structure

2. SELECTION OF COMPONENTS

2.1 Stepper motors

A stepper motor (or stepping motor) transforms applied voltage pulses into discrete motions called steps. It allows precise control of position and speed without, generally, the need of feedback. This reduces the complexity of the control. Figure 2 describes a simplified stepper motor – control system. The stator windings are excited according to groups which are called phases. Motors can be of 1, 2, 3, 4, or 6 phases. The number of pole pairs determines the rotation angle for each step or the number of steps for each revolution. Depending on the excitation to motor phases, the motor will operate in one these 3 modes: Full stepping, Half stepping, and Microstepping. The rotation director is decided by the order of winding excitation.

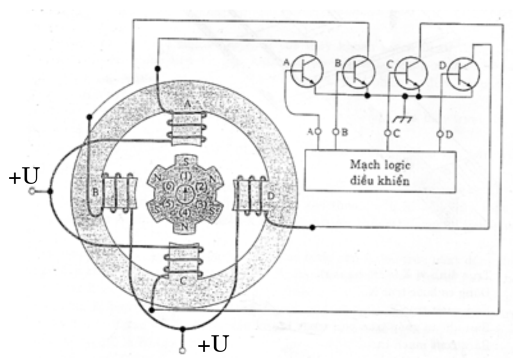

Fig.2 Stepper motor and control

We selected the 3-phase stepper motors VRDM 397/50 LWB of SIG-POSITEC (Germany). The 3-phase type is a tradeoff between 2-phase and 5-phase motors. It has large power, simple wiring connection, and can reach 200/400 steps/rev (same as 2-phase type) or 500/1000 steps/rev (same as 5-phase type). Besides, the number of steps can be increased 10 times (microsteps) to become 2000, 4000, 5000, or 10,000 steps/rev.

Some main specifications are as follows:

- Number of steps per revolution (z): 200/400/500/2000/4000/5000/10000
- Rotation angle (α^{o}): 1.8/0.9/0.72/0.30/0.18/0.09/0.072/0.036
- Sustaining torque (M_H): 226Ncm
- Nominal current/winding (I_W): 1.75A
- Supply voltage (U): 325VDC

2.2 Coupling

The coupling between motor axis and load has a strong impact on the operation of the motor and efficiency of the system. The manufacturer recommends anti-twisting coupling for high resolution positioning systems. When the precision requirement is not so severe, flexible coupling is acceptable, with an advantage in that it can compensate for the linear offset of the axes.

2.3 Power drive

Power drive is a power electronic circuit to supply switching currents to motor windings. In figure 2 the power drive is represented by 4 power transistors. Actual power drivers are more complex. We used Power drive D901 (single) and D902 (dual) of SIG-POSITEC (Germany). The automatic drilling machine comprises 3 stepper motors for X, Y, Z motions (Figure 1). Power drive D901 is for Z-axis motor, while D902 is for X-axis and Y-axis motors. Figure 3 shows the system and

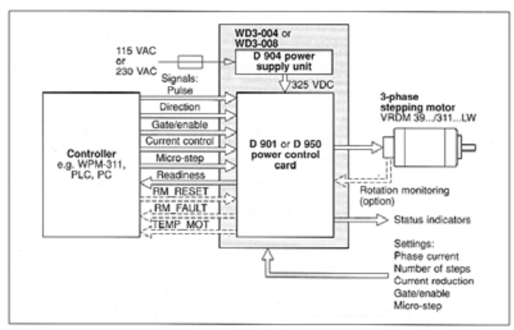

Fig.3 Controller – Power drive – Motor system

Figure 4 shows the block diagram of D901. D901 and D902 operate at supply voltage from 250VDC ~ 380VDC and have maximum consumption of 1,6A and 4,0A respectively.

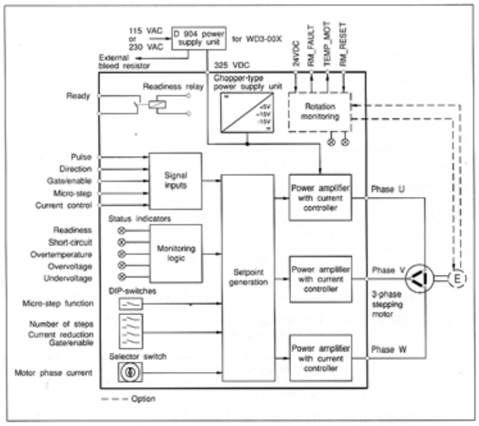

Fig.4 Block diagram of Power Drive D901

2.4 Electro-mechanical positioning linear axes

An axe converts rotational motion of motor into linear translation. We chose high precision axes from FESTO (Germany) detailed as follows:

- For Y axis translation: DGEL – 40 – 500 – SP
- For X axis translation: DGEL – 40 – 400 – SP
- For Z axis translation: DGEL – 25 – 300 – SP

The axes use internal spindle and ball bearings, and transfer internal linear motion to an outside slide which moves along a rigid guide.

The axes can be placed at any direction, and can operate in sliding mode (load presses onto slide) or yoke mode (load pulls on slide). Some main specifications are as shown in Table 1.

Table1 Some main specifications of linear axes

	DGEL-40-500SP	DGEL-40-400SP	DGEL-25-300SP
Axis size (mm)	40	40	25
Motion range (mm)	500	400	300
Repetition precision (mm)	+ 0,02	± 0,02	± 0,02
Translation constant (mm/rev)	20	20	20
Maximum sliding speed (m/s)	1,0	1,0	0,5
Maximum torque (Nm)	2,1	2,1	0,45
Weight (kg)	6.4	6.4	2.1

2.5 Error

Consider for example a motor runs at 2000 steps/rev then with translation constant of 20mm/rev the linear translation per step can be found to be 10^{-2} mm/step. This sensitivity is more than enough for hole tolerance.

With repetition error of ± 0,02 mm/rev, the repetition error for each step at 2000 steps/rev speed can be found to be ± 10^{-5} mm/step, which is negligible. Moreover, the way the drill moves does not lead to the accumulation of repetition error.

3. CONTROL CIRCUIT

3.1 Controller

Figures 3 shows that we need a logic controller which can be a computer, PLC, or microcontroller (MC). Microcontroller was chosen because it is cheap and satisfies control requirements. AT89C51 of ATMEL is 8-bit microcontroller of CMOS technology with 128 byte RAM, 4k byte flash ROM, 32 I/O lines organized into 4 ports, 2 16-bit counter timers … The flash ROM stores the monitor program and hole data file (for NC system – see later), and the RAM is for the controller to run programs. Each hole needs 3 bytes of data, the flash ROM can thus store data for about 1000 holes.

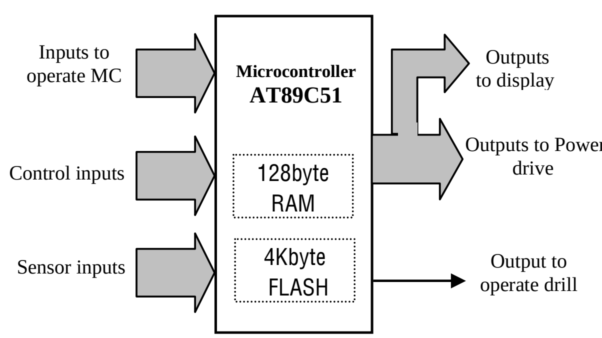

Fig. 5 Microcontroller and inputs - outputs

Figure 5 shows the microcontroller and five signal groups:

- Inputs to operate the microcontroller.
- Control inputs.
- Inputs from sensors: Each X, Y, Z linear axis is equipped with two magnetic proximity switches.
- Outputs to power drives.
- Output control to drill.

3.2 Drilling motor

The motor is also a very important part of the whole system. It must satisfy requirements such as: high power, strong starting torque, high revolving speed (e.g. 10,000 revolutions/minute). The motor and bit axes must be on the same vertical direction.

3.3 Display

The display of X-Y coordinates and of some operation conditions are necessary for monitoring the system.

3.4 Stabilized power supplies

The power source includes:

- 325V – 10A for the 3 power drive
- 26,5V – 3A for the drilling motor
- 24V – 1A for the supplying control logic levels to the power drive
- 12V – 1A for the limit sensors and display block
- 5V – 1A for the microcontroller

4. NC AND CNC SYSTEMS

The automatic drilling machine can be configured as a NC (Numerical Control) or a CNC (Computer Numerical Control) system.
In NC system the PCB file of computer is converted to hole data file which is then converted to the form of data appropriate for the microcontroller (MC). This data and the monitor program are loaded into MC flash ROM. The control of the drilling machine is from the MC not from the computer. When we want to change the PCB pattern, then the new PCB file is downloaded to the flash ROM again. Figure 6 describes the NC system.

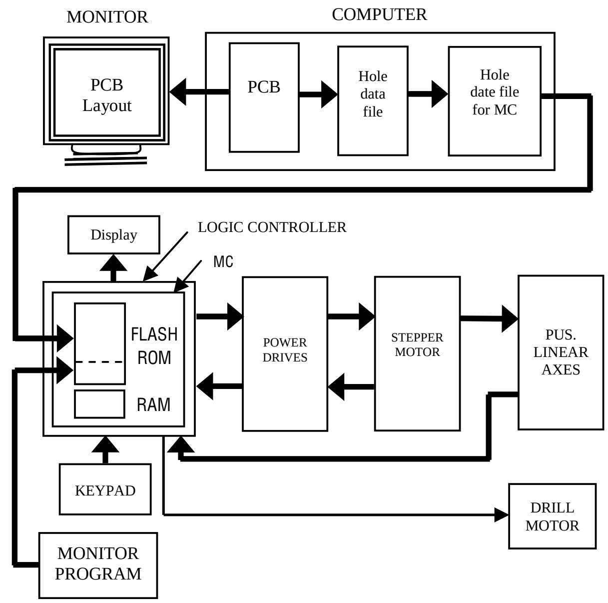

Fig.6 NC system

In CNC system the computer directly controls the drilling machine and receives feedbacks from it. The MC is still useful. The computer displays X-Y coordinates of the drill and several other operation states.

5. CONCLUSION

We have designed and built an automatic PCB drilling machine having a rigid mechanical base, robust electro – mechanical parts, and an effective control electronic circuitry. Still there are some refinements and improvements need to be done.

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