PCB Drilling Machine (5)

part 5 (final): ready to go!

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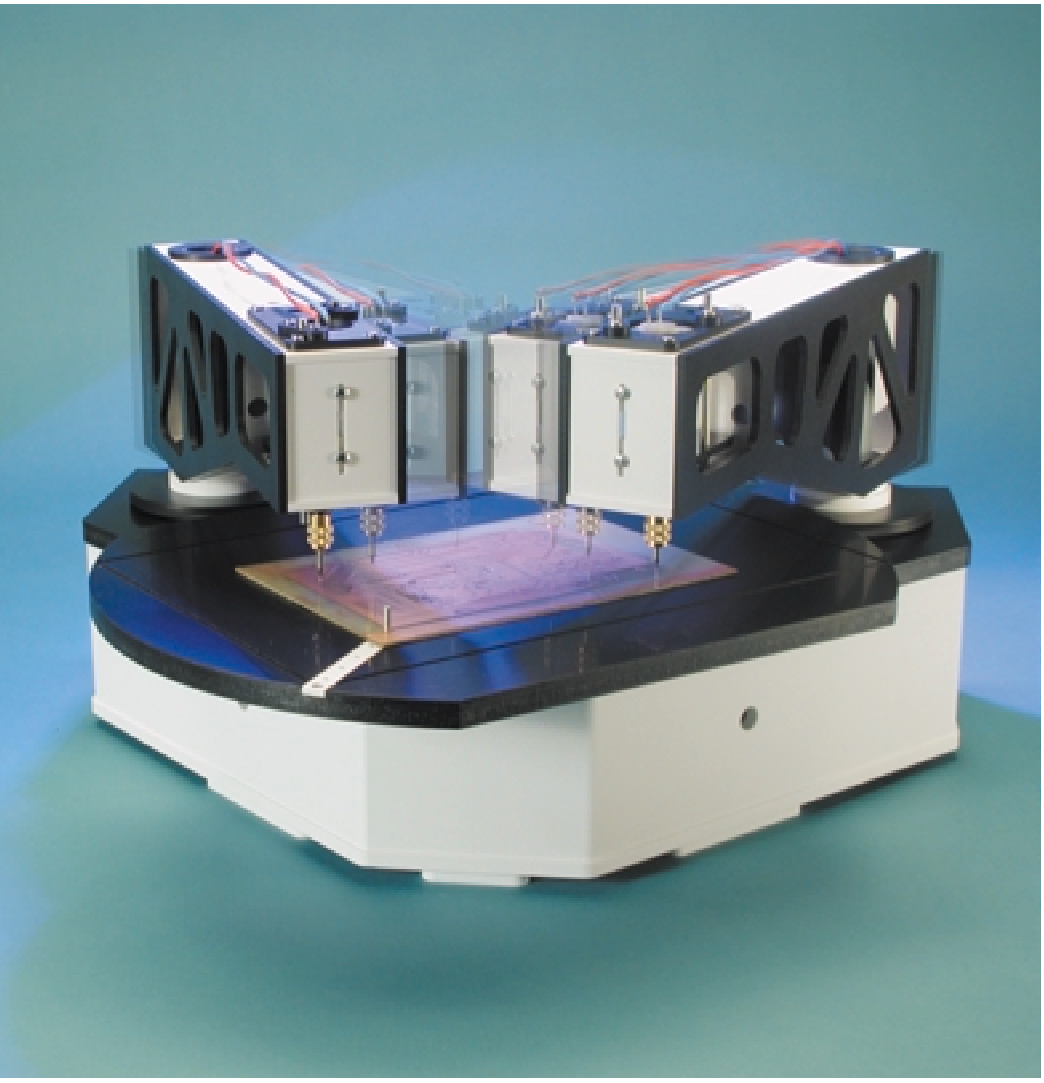
In this final part on the construction of the PCB drilling machine, all its functions are tested and the machine is calibrated. The machine is then ready for its first job.



By the time you read this, the first PCB drilling machines have already been delivered — and perhaps also assembled. It is therefore high time that our description of the machine be completed. All that remains is the calibration of the machine. The machine must be calibrated before the driver software is able to determine the reference point, calculate drilling coordinates correctly, position the arm(s) and turntable and raise and lower the drilling head. A number of position sensing switches play a key role in initialising the machine. In this final part we describe a complete calibration procedure for the arms and turntable with the aid of the TanBoTest software, and the use of the TanBoDrive driver software for drilling PCBs. Please note that the German working title of the project, 'Tanbo' (for Tangential Bohrer) is retained in the names of the files and programs developed for the project.

Position sensing swiches

In the machine enclosure there is an optical switch situated just between the two drive shafts for the tool arms, which operates on the reflective principle. **The position of the turntable** and of tool arms 1 and 2 can be determined using this switch. The sensor consists of a light-emitting diode (LED) which emits infrared light vertically upwards, and a phototransistor, also pointing upwards, which detects when a reflective object passes in front of the LED. For this reason there is a reflector made of metallised foil on the pointer attached to the tool arm drive shaft, as well as on the underside of the turntable.

This reflective light switch operates using unmodulated infrared light and is therefore highly prone to interference from other IR sources such as daylight, artificial light, and even the light from cigarette lighters! While under the circular part of the turntable the switch is completely covered, but the turntable's two flattened sides, which are opposite one another, can let stray light in. And why is the turntable not a perfect circle? It saves a little material, but more importantly this is the only way that access can be provided to the sensor to allow for inspection and cleaning.

If stray light should interfere with the sensor, the turntable need only turn until the sensor is again in the dark, and then continue to turn until the sensor sees light again **but only over a narrow angle**. In this way, the position of the reflective foil can be found. Upon subsequent rotation in the opposite direction the transition from light to dark must be found at the same point. Once the system has determined the position of the turntable, it then immediately knows where the flattened sides are that give rise to the risk of light interference: the software takes these into account.

The process for **initialising the tool arms** is simpler, since in each case the sensor is covered by the turntable and is therefore protected from stray light. The system looks for (and finds!) the reflecting position of the arm.

If two arms are in use simultaneously, there is a problem that must not be overlooked. If both arms attempt to travel to their end positions at the same time, there is a risk of collision. This difficulty is overcome elegantly as follows: the Windows software notes the position of

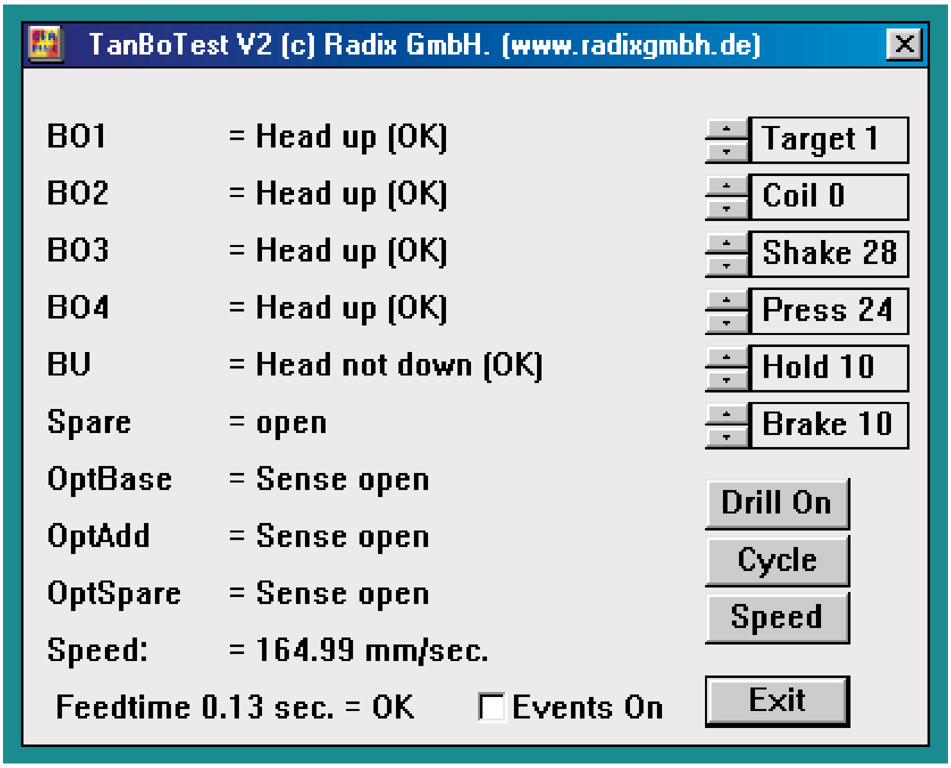


Figure 1. The TanBoTest utility tests the various microswitches and determines the operating parameters to be stored in the configuration file.

the two arms at the end of a run and stores the relevant information in a temporary file. When the program is next run, the file is loaded, and so a collision can be avoided. If the program terminates abnormally (which can be the rule rather than the exception under Windows!), this file will be found to be missing the next time the program is run. In this case the program enters manual control mode. A graphical representation of the drilling machine appears on the monitor: the tool arms can be dragged into position on the screen using the mouse so as to represent the actual state of the machine. This need not be absolutely accurate, although the machine will rely on your input.

Two microswitches are provided in the tool arms to determine which of three possible states the drill head lift mechanism is in.

State 1: Drill head lift mechanism at the top of its travel, in rest position. If no current flows in the solenoid, the force of the spring built into the lower part of the arm must push the drill head to the top of its travel and thus open switch BO (BO is a normally-closed contact). If the arm is not fitted, there is no BO switch, and the corresponding switch inputs (BO1-BO4) on the circuit board are open. The software can check each arm individually to determine whether the corresponding drill lift mechanism is in the up position.

State 2: Drill head lift mechanism is lower position, determined via BU. All BU contacts of all arms are normally open and are connected in parallel. This can work because only one head is allowed to be in the down position at a time. Safety logic in the GAL prevents multiple drill head lift mechanisms from being actuated at once. And if (because of a mechanical failure) more than one drill head should be down at the same time, this can be detected via the BO contacts.

State 3: This state is between the other two: neither up nor down. Assuming nothing has gone wrong, this can only happen during motion of the drill head. If this state occurs while the head is not in motion, the drill lift guide is probably jammed.

During drilling the Windows software can measure the time between the closing of the upper switch and the closing of the lower switch, which gives the time taken to drill the hole. A broken drill can be detected by this

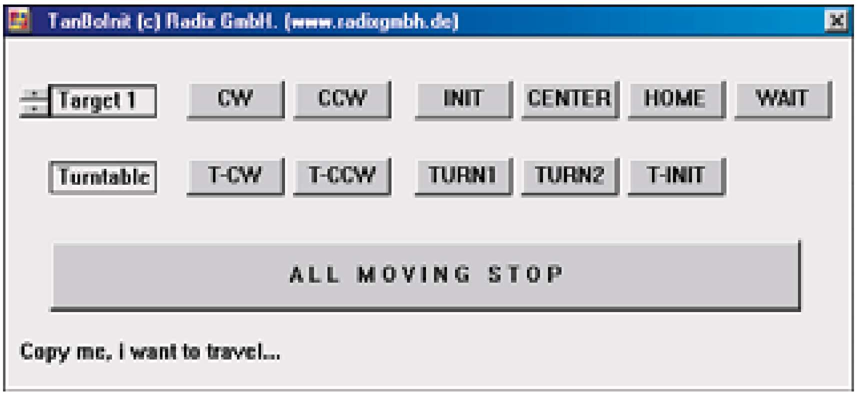


Figure 2. Initialisation program for calibrating the arms and turntable.

time being too short, and an overly worn drill can be detected by this time being too long. If it takes longer than five seconds to drill a hole, the controller automatically switches off the drill lift mechanism and the drill motor.

The first test

The *TanBoDrive* driver software requires that the drilling machine be fully functional, both electrically and mechanically. The input data — in this case drilling data in Excellon format — are specially processed and transformed into the required commands, in the form of motion commands and drilling commands, to be sent to the microcontroller. More than this *TanBoDrive* cannot do. Linear interpolation, as required for interpreting HPGL-format files, is included (otherwise the machine could not even move from hole to hole), but HPGL import is disabled and will only be enabled when the previously-mentioned milling arm has been thoroughly tested. *TanBoDrive* should be compared to a printer driver: if the controller board or the mechanics are not in order, the program simply gives up.

First, then, servicing and diagnostic software is required to test all the functions of the controller board and the connected units. The various switches are particularly important, since they must be correctly wired as well as correctly fixed. All components must first be made to work as intended and all tests must be passed before we can move on to drilling a circuit board.

This requirement is met by the *TanBoTest* test software (**Figure 1**). When the software is started a dialogue box appears showing the states of all the switches, updated every 300 ms. The optical switches can be tested with a finger or any reflective object. The drill motors can also be turned on and off, and the lift solenoids can be supplied with a selectable current, in order to help check (and, if necessary, improve) the smooth running of the guides. The program, freely available from this url

www.radixgmbh.de/deutsch/menu_bestellung.html

is self-explanatory and shows the states of all the switches. It is essential to check the messages in the dialogue box and to test the three positions of the drill head lift mechanism. Test the optical switches with a reflective surface and with stray light. Set *Target* to 1 and push the drill head down: you should see activity on BO1 and BU (but not BO2); likewise for the other target. Using the box marked *Coil*, adjust the solenoid current to find the value required to drive the drill head down. The numbering of the targets is clearly defined: looking at the machine from the longer side and above, the left-hand arm is tool arm 1 and the right-hand arm is tool arm 2.

The switches are so vital to the operation of the machine that the switch inputs to the controller board are not fitted with a socket, but rather soldered directly. Although a little more tedious to assemble, the connection is more secure. A length of black PVC insulating tape should be used as a strain relief on the cable which comes from the drive shafts, so that the connecting pins are not under mechanical stress. Ensure also that the cable is free to move.

Here is a summary of all the functions of the test software:

The *Target* box selects between output drive stages 0-3 for drill and coil.

The *Coil* box can be set from 0-65 to control the solenoid current from 0 (off) to 65 (100 %) for the output stage selected under *Target*. Beware that the original solenoids are overloaded at the 100 % setting and cannot run continuously at this current. A duty cycle of about 30 % is possible. Continuous operation is possible at a setting of 26. The software switches the coil off if the setting is left unchanged for 5 s.

The *Drill On* button switches the output drive for the drill motor of the selected target on and off.

The next four boxes are to do with the drill cycle. Each target has its own press and brake values, while the shake and hold values apply to all four targets. Each click on the Cycle button initiates a drill cycle with the selected parameters.

The *Press* box sets the force with which the drill is pushed down on the circuit board. This value — to a certain extent — affects the speed of drilling. If the value is too small, the solenoid will not exert enough force to drive the drill down. If it is too big, the drill can in extreme circumstances be damaged when it hits the circuit board. The value should be set to suit the drill: a value between 24 and 40 is normal. If satisfactory operation can be obtained with a value below 25, it is a credit to the conscientiousness and care with which the assembly has been built: congratulations!

The *Brake* box sets the braking value needed to cause the drilling head to come to a gentle stop at the end of its upwards travel. If the value is too high, the head guide will rebound down before finally coming to a halt; if on the other hand the value is too low, the upper switch will be (ab)used as a mechanical endstop, which is definitely something to be avoided. Find the setting where the head does not rebound and then add one or two to the value.

The *Hold* box sets the time (in units of 52 ms) for which the drill remains down after the circuit board is drilled through. Too short a time leads to swarf not being fully cleared from around the hole on the underside of the board, while if the time is set too long, it is simply time wasted. The default value of 10 (i.e. 0.52 s) is a good typical value for clean holes of all sizes.

The *Shake* box is aimed at the automatic clearing of faults. If for example the guides are very dirty and not running smoothly, the force of the spring may not be enough to lift the head fully up and operate the upper switch. This fault can be simulated by pushing the guide down a couple of millimetres so that the switch BO indicates *'Head not up'*. If the head stays in this position when it is carefully released, then the fault condition has been replicated. The shake value controls how the head is driven down a small amount and then released, without braking, so that it springs back. The force with which this is done must of course not be so great that the drill hits the circuit board when it is not running.

The *Cycle* button initiates a complete drilling cycle on the selected target. The feed time is measured and displayed (minus the Hold value). If the cycle completes without error, *OK* is displayed; otherwise, *Error* is displayed. If there is an error with a feed time of around 4.5 to 5 s, this indicates that the head never reached the lower position: this condition can be simulated by setting Press=0. With a feed time of around 0.5 to 1 s, the fault is that the upper end position was not reached: this condition can be simulated as described above with Shake=0.

The values established for the drill cycle using the *TanBoTest* program are recorded in the configuration file.

The *Speed* button sends data at a steadily increasing rate to the controller until the PC's processor can no longer keep up with the data stream and the controller's FIFO empties.

The *Speed* indication in mm/s refers to the speed of interpolation on two axes, for example to simultaneous motion of the turntable and the tool arm at the given speed. The mechanical maximum speed limit is around 80 mm/s. If the speed test gives better results then there is a surplus of processing power, and further axes can be made to move simultaneously. When trying the speed test, the stepper motors should not be connected!

The *EventsOn* check box, when checked, gives up some processor time during the speed test to the operating system, and hence to other processes. This is done to allow other tasks to make progress. The *TanBoDrive* control program uses a dynamic algorithm to determine how much processor time to allow the operating system, ensuring as necessary that the system does not come to a complete halt.

At start-up, the software must be informed of the address of the LPT port to which the controller is attached. This setting can be obtained from the Windows system information, and is generally $0378\text{-}037F_{HEX}$. Open an ASCII text editor with an empty file and enter on the first line the first of these numbers (here 0378). Now press Return twice and save the file as *lptaddr.txt* in the same directory as *TanBoTest*. This file is processed by all the drilling machine programs and must be placed in the same directory as all those programs.

An important part of the test program is the measurement of the transfer rate for data streams over the Centronics interface. See the text box for further details.

Adjusting the arms

After you have checked the operation of the hardware — and, if necessary, corrected it — using the *TanBoTest* program, the machine must be adjusted and calibrated. Calibration — also known as setting the zero point — presents no difficulty with a linear machine, but how can we adjust something that is circular and does not have a start or an end? Further, several of the components of the drilling machine can be assembled in different ways: for example, the drilling axis can be moved to and fro by several millimetres before being firmly screwed down. In order to calculate the X/Y coordinates exactly, the length of the arm must be known absolutely precisely. It is all done, as we said in the first article in this series, without precision measuring instruments of any kind.

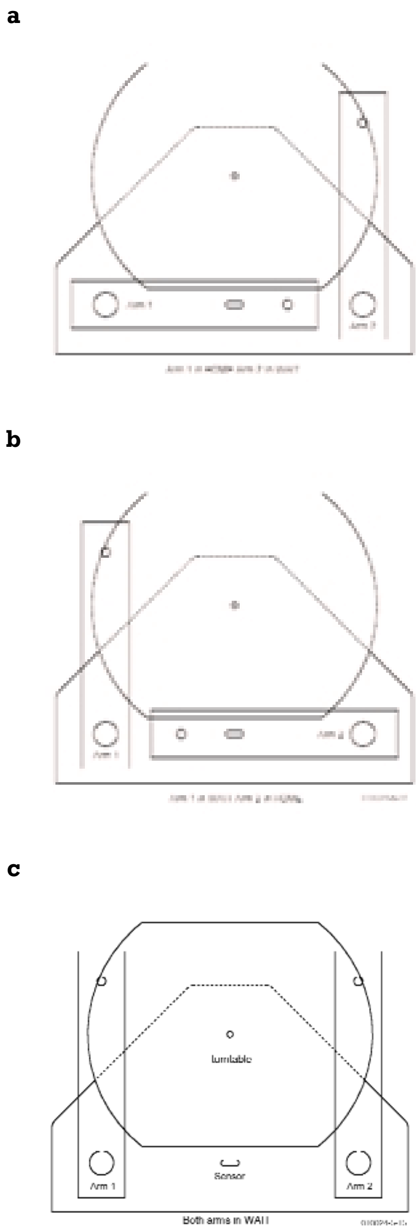


Figure 3. The arm positions for calibrating the turntable: home/wait (a), wait/home(b) and wait/wait (c).

All that is required for exact adjustment is the *TanBoInit* software (**Figure 2**), which also uses the *lptaddr.txt* file. Note: if at any time during the adjustment procedure anything untoward should happen, or if you think from the way the arms are moving that a collision is imminent, click on the 'emergency brake' ALL MOVING STOP: the machine will come to an immediate halt.

First we calibrate the arms, and then the turntable. The other way round is not possible, because the turntable can only be set up with properly calibrated arms. Each arm can be moved at will using the buttons CW (clockwise) and CCW (counterclockwise). In *TanBoInit*, as before, which of the arms 1-4 is moved can be set via the *Target box*.

First check that all the tool arms turn appropriately in response to the CW and CCW buttons. Select also the targets for which an arm is not fitted, and press CW and CCW. In these cases nothing should move.

The ordering of the target numbers has already been checked in the test program. The four BO switches are shown in a column above one another. If you push down the head on arm 1, you should see activity on BO1 and not on BO2. Check this very carefully, since otherwise the collision detection will not work. The drives are extremely powerful and are easily capable of destroying one another!

The turntable has its own CW and CCW buttons, while the *Target* box remains always assigned to a tool arm. Before an arm can be calibrated, the turntable must be rotated so that the reflective light switch is off.

Begin with the calibration of arm 1 (target 1). Move arm 2 (if fitted) to the WAIT position, as shown in **Figure 3a**. In the kit of parts which contained the brass chuck, you will find a short polished metal pin, 20 mm long, left over. This is the only calibration tool required. Push this pin as far as possible, without using excessive force, into the hole in the aluminium shaft at the centre of the

Buffer Underrun?

The drilling machine controller software forces Windows to operate in real time. Although Windows can output data very quickly, it cannot coordinate the timing of the output exactly, and for this reason the controller includes a FIFO (first in, first out) memory which allows the transmitted data items to be brought back into step with one another.

This works perfectly as long as we can ensure that the data stream from Windows never stalls for so long that the FIFO becomes completely empty. The FIFO has 35 slots, from which we can make the following example calculation.

Let us suppose that a stepper motor is to be turned at the rate of 500 steps per second. The motors used in the drilling machine have an angular resolution of 1.8°, and so this corresponds to a rotation rate of 2.5 rotations per second. Since the following gearbox has a ratio of 200:1, the output shaft turns through an angle of 4.5° per second. The circumference of the circle swept out by the machine is 1510.6 mm, and so the head moves at a speed of 18.88 mm/s.

What data rate is required for this? The specification of the Centronics interface allows for at least 20000 bytes/s. On an older PC (150 MHz Pentium) the bandwidth was measured at around 46000 bytes/s.

Each motor step requires exactly one transfer, and so the required 500 transfers per second occupy a mere 2.5 % of the available bandwidth. Bandwidth is therefore not a problem.

At 500 steps per seconds each step lasts 2 ms. The FIFO, with its 35 slots, can hold 70 ms of data. In these 70 ms the processor we used runs for 10.5 million cycles. If these cycles are consumed by Windows and the FIFO cannot be refilled with data in time, then there will be a break in the data stream.

For this reason it is not possible to run programs in parallel with the drilling machine that load the system heavily or which consume practically all its processing power.

How can we check that the data stream is in fact continuous?

A control signal on the controller board indicates when the FIFO is empty.

This signal is taken to pin 12 of the Centronics interface (paper empty) and is asserted when all the bytes in the FIFO have been processed.

So why is it so important to have a continuous data stream? Stepper motors that are to be used at a high stepping rate must be brought gradually up to the desired target speed using a specially-designed ramp function. The moment of inertia of the rotor is so great that it cannot follow a rapid speed change and drops steps. This effect is much more noticeable when starting than when stopping, and depends on the individual motor and its driver stage. So, if the pulses are suddenly stopped while the motor is still turning, the rotor will not come to an immediate halt, but rather jump on one or two positions because of its moment of inertia. That does not matter, or course, if the system has feedback, for example in the form of an encoder on the drive shaft.

And the solution? The best answer is not to allow interruptions in the data stream. Before issuing each motor pulse command, we can check whether the controller FIFO signal is asserted, indicating that the FIFO has emptied. Then — if we know the characteristics of the motor — we can decide on the basis of the previously-set command rate whether the motor might have got out of step (this can only happen above a certain, relatively high, rotation speed), and whether the drive in question should return to the limit switch position to recalibrate itself. If this behaviour recurs—that is, if you notice that the machine is returning to its reference points too frequently—then either you will need to use a faster computer, reduce the load on your system, or reduce the pulse rate for the motors.

None of this is really a problem, but the unnecessary recalibration movements do affect the average speed of the machine and hamper the system somewhat. A reduced motor step rate can increase the overall speed of the system, if it reduces the number of recalibration movements.

And there is an even better solution: the FIFO memory can be expanded, as used to be done with print spoolers. Exactly the same principle can be applied to the drilling machine. With a small static RAM of for example 8 kbyte the capacity of the FIFO can be increased to 8.25 seconds of data at the frequency of 500/s mentioned above.

This extra FIFO would take the form of an additional unit; it is not possible simply to change the microcontroller. Microcontrollers with a large amount of on-chip RAM are significantly more expensive. The additional module could be supplied with power via the OptSpare pin (5 V DC). Another possibility would be a small module on a printed circuit board to fit in the microcontroller socket which includes the extra buffering.

If such an idea is implemented, you will be able to read about it either in Elektor Electronics or on the drilling machine website.

turntable. This hole is machined extremely accurately: on pulling out the pin you should hear a satisfying 'plop'.

Fit the largest insert into the chuck on arm 1 and tighten the nut loosely. Loosen the eight screws in the head guide bearing block. There are eight oval places where the 4 mm shafts for the head guide assembly are fitted. Do not remove the screws completely, but only loosen them so that the head guide assembly can be moved laterally to and fro.

Using the CW and CCW buttons, bring arm 1 to the centre of the turntable until the chuck can be pushed down exactly over the pin. The head guide assembly must have enough play that no force is required to push the arm into the correct position. The precision obtained by this procedure is improved if the last command given is always CCW.

Now press the head assembly fully down and tighten the nut fully. The entire assembly is held vertically in the centre of the table by the steel bolt and so the bearings are forced into their position. Now, with particular care, tighten up first the lower, and then the upper bearing screws, initially gently, and then tightly. The nut can now be removed. The head guide now glides (we hope) smoothly up. The smoother this motion, the faster the machine will be able to drill.

Two important things have been done here: the head guides are now perfectly vertical and the arm length is set to exactly the desired value. One of the polar coordinates — the length — is now done. The coordinate that remains, the angle, is handled by the software. Press the *INIT* button for the arm that has just been calibrated. The arm automatically moves out until its pointer is located over the optical sensor. The software now knows exactly the number of angular steps between the end point and the mid-point. The mid-point corresponds to an angle of 45°.

Now, to test the middle position, remove the bolt from the central hole and fit it directly in the chuck. In the software, press the *CENTER* button, and the arm should move to the middle position. When the axle is pushed down, the pin should sit perfectly in the hole. Release the chuck, allow the head to slide up, move the arm away and then remove the pin from the hole.

If the positioning is not perfect in this experiment, the arm angle can be adjusted using the CW and CCW buttons. The last command should, as before, always be CCW. After each adjustment the INIT button must be pressed again to store the new reference values. After the button is released, the arm travels immediately back to the sensor position. Once the mid-point positioning is to your satisfaction, press HOME. Target 1 now travels to its home position. The procedure with the second arm is the same: first, as shown in **Figure 3b**, bring arm 1 out of the danger area and click on *WAIT*. When calibration is finished, be sure to keep the bolt in case you wish to recalibrate the machine after modifying or expanding it.

Turntable calibration

If you have calibrated two arms, then arm 2 will be over the sensor and arm 1 will be in the wait position. Press *WAIT* also for arm 2 so that both arms are vertical and parallel to one another. If you have only calibrated one arm and this is in the home position, then you should also press *WAIT*. To calibrate the turntable put the approximately 8 mm long registration pin from the bag which contained the chuck into position 1 of the registration guide: this is the outermost hole on the rim of the turntable. Set target to 1 and press *TURN1*. Arm 1 makes a small movement from its waiting position towards the turntable.

With the *T-CCW* button (NOT *T-CW*!) turn the turntable so that the bolt in the registration guide lies under the chuck. Now with the *T-CCW* and *T-CW* buttons you can carry out a fine adjustment so that the chuck slides over the bolt when the head guide assembly is pushed down. The last command should again be a *T-CCW*. When you are happy with the positioning, press *T-INIT* and then the button *TURN2*. The turntable turns about 140° counterclockwise. At the same time the tool arm also moves and the two come to the second possible intersection point. The mathematical background to the positioning scheme for the drilling machine is shown in a Flash animation at this url

www.radixgmbh.de/deutsch/
menu_link.html

When the turntable and the tool arm come to a halt, the test pin should once again slide into the chuck smoothly and without undue force on either part when the head guide assembly is pushed down. Once the calibration of the two turntable points is complete, press *T-INIT* again: the turntable will turn to the point where the optical switch is activated, the *HOME* position, and then the tool arm moves to the *WAIT* position.

If a second arm is fitted, the calibration procedure should be repeated. Although this is unnecessary from a mathematical point of view, it helps to compensate for tolerances in the system.

When the program is exited by clicking on the cross at the right-hand end of the title bar, the file *TanBo.def* is written to the hard disk. This file contains all the measured parameters which are used by the control programs. Without *TanBo.def* the *TanBoDrive* program cannot be started.

Setting up the machine also requires checking the planarity of the turntable. The more level the turntable, the less packing material is required between circuit board and turntable. The turntable is fixed to the drive axle via a generously-dimensioned fixing flange in the form of a circular steel disc by three M6 screws, easily accessible from above. By turning the turntable you can test to see if the surface moves up and down. Mark the 'deepest' point and dismantle the turntable. On the marked point, on the flange, lay a scrap of paper wetted with salad oil. The reason for the oil is that it makes the paper more dimensionally stable so that the thickness of the paper is not affected by humidity. Screw the turntable down onto the flange, tightening the screws fully. After at most two or three trials you should be able to turn the turntable without measurable vertical wobble.

The packing material — a thin piece of card or a couple of sheets of paper — is needed because drill points are in general not cylindrical but rather conical in shape. The card must therefore be thick enough for the point of the drill. The maximum feed distance, and so the lowest position of the drill, can be set by an adjustment screw at the front of the tool arm.

Drill!

The machine is now calibrated and ready to drill your first printed circuit board. The basic requirement (apart, of course, from an etched but as yet undrilled circuit board) is a drilling file in Excellon format. Practically every printed circuit board layout program is capable of exporting a drilling file in this format. Among other things, the Excellon file contains the Cartesian (or X/Y) coordinates of each hole specified in the layout. The file also contains control information and (possibly in a second file) information specifying the diameter of the hole to be drilled at each given coordinate pair. This file can be opened, examined and even modified using a normal ASCII text editor.

The *IMPORT* button in *TanBoDrive* (**Figure 4**) opens a standard Windows file selection box and waits while the Excellon file is selected. The file is searched for the two points used in the reference system; the diameters specified for these holes are not used. Once the two coordinate pairs are found by *TanBoDrive* they are used as reference points, but, of course, not drilled. It is necessary to specify in which of the two reference points the fixed pin is fitted: for this reason a thumbnail of the drilling pattern is shown in the dialogue box.

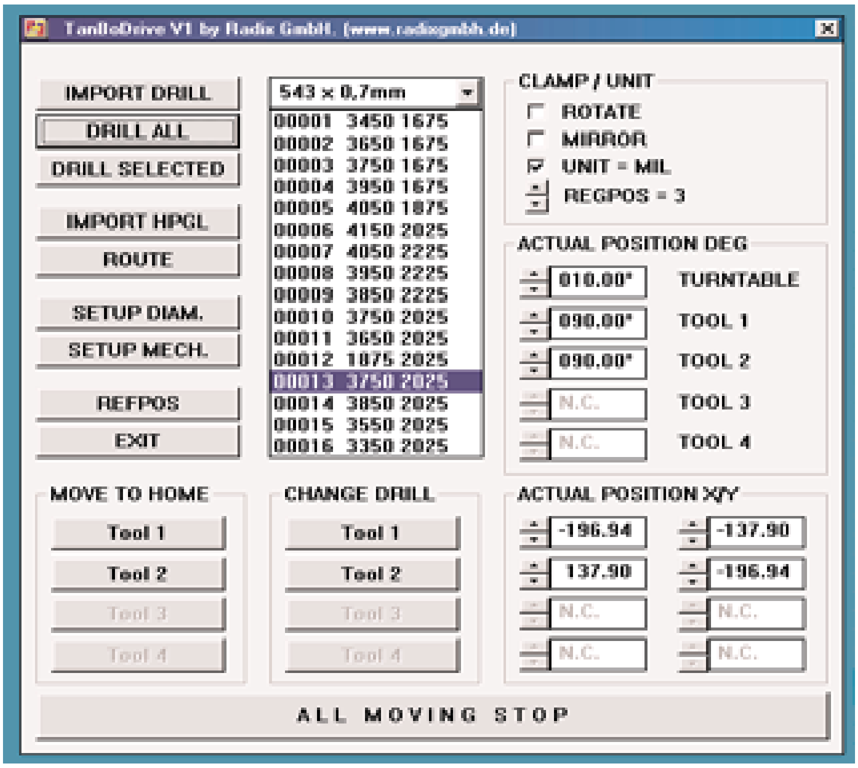


Figure 4. In the driver software TanBoDrive an Excellon file can be imported and the orientation of the circuit board can be set: ready to go!

Place the ready-etched printed circuit board on the turntable and select one of the twelve holes in the registration system. Fit the circuit board over the short metal pin and slide the free pin so that it fits in the second hole in the printed circuit board. Push the free pin outwards a little so that the circuit board is better centred. If the circuit board is badly warped, it is necessary to hold the corners down with adhesive tape.

In the program select in the *FixPoint* box the number of the registration hole to which the circuit board is fitted. The positions are numbered from outside (greatest radius) to inside from 1 to 12. There is no need to count: with each click the drilling pattern picture is updated so as to show the selected pin position. You can therefore check at a glance that the number is set correctly.

At this point there are two things that might go wrong. First, the circuit board might be rotated 180°: the hole shown over the fixed pin in the dialog box is in fact over the moving pin, and vice versa. Click in the check box marked *ROTATED* and the circuit board will be shown correctly on the screen.

Some programs produce drilling information as viewed from the reverse of the board (as the copper foil patterns are shown in the component mounting plans for *Elektor Electronics* printed circuit boards). Since the drill tends to wander if the board is not drilled from the copper side, the *REFLECTED* check box must be clicked to correct the situation.

There is only one thing left to do: click on START. The drilling machine moves the first tool arm into the drill change position and displays an information box with the required diameter of drill. Fit the appropriate drill in the chuck and click on OK. The machine will now run, drilling at each point requiring the first drill size. If a second arm is fitted, it will meanwhile move to the drill change position.

Further requests follow, depending on how many different sizes of hole are to be made or if multiple identical circuit boards are to be drilled. It is unnecessary to describe all these here, since the software is very user friendly and practically self-explanatory. If something should go wrong, or if any difficulties are encountered, a platform where you can exchange experiences with other users and praise or berate the developers of the machine is provided at the Radix homepage.

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Note:
Kits and individual parts for the PCB Drilling Machine are supplied by the author via the Radix GmbH company in Germany. At the time of writing, negotiations are under way with C-I Electronics to handle international distribution of the mechanical kits, possibly including the Elektor Electronics driver board. Further information from C-I Electronics, P.O. Box 5514, NL-3008-AM, Rotterdam, The Netherlands. Fax (+31) 10 4861592, email dil@euronet.nl. Website www.dil-dos.nl