High Stepping Automatic Coil Winder

An Intro to Precision Positioning

This Month's Projects

The Fuzzball Rating System

To find out the level of difficulty for each of these projects, turn to Fuzzball for the answers.

The scale is from 1-4, with four Fuzzballs being the more difficult or advanced projects. Just look for the Fuzzballs in the opening header.

You'll also find information included in each article on any special tools or skills you'll need to complete the project.

Let the soldering begin!

Have you ever thought of a project where you needed to position an object with great precision? Maybe you wanted to build a precision milling machine or maybe a computer plotter. My introduction to precision positioning came about from a need to wind wire coils for solenoids. Coils are used for all kinds of electrical applications - from solenoids for electromechanical actuators to coils for electric motors.

My first coil winder (shown in Figure 1) was just a DC motor turning a coil form. It required a steady hand to lay down the wire on the coil. The winder really had no idea of how many windings were on the coil. What I wanted was an automatic coil winder that I could set up, walk away from, and when I came back, have a finished coil. Even if you do not need to wind coils, this project provides a good introduction to precision positioning using stepper motors under computer control.

The automatic coil winder in this article uses stepper motors to position the wire in increments of 0.000651 inch. The motors are controlled through a personal computer's (PC) parallel interface. The Visual Basic software automatically estimates the wire length and stops the winding process when the desired number of windings is reached. The coils are wound without any human interaction except to mount the coil form and to remov ished coil. The automatic winder is winding a number of identical coils.

Stepper Motors

Stepper motors are well-equippe project where rotation and lateral have to be controlled with great p There are many stepper motor c available for doing computer nume trol (CNC) machining; however, for t ect, I decided to build a simplified motor controller from scratch. I de use a PC as the "brains" of the contr to use the PC parallel port to carry th signals. Visual Basic (VB) was the l used to program the PC.

A unipolor stepper motor has tw tapped coils. A unipolar motor has fiv eight leads. The motor I chose has si identified the two center taps by m resistance with a suitable ohmmeter. T ance from a terminal to the center ta the resistance of the two terminals o With the center taps identifi BLUE&WHITE and BLACK&WHIT remaining wires must be the coil termin

For the motor I chose, each ener a coil should rotate the shaft 7.5 d

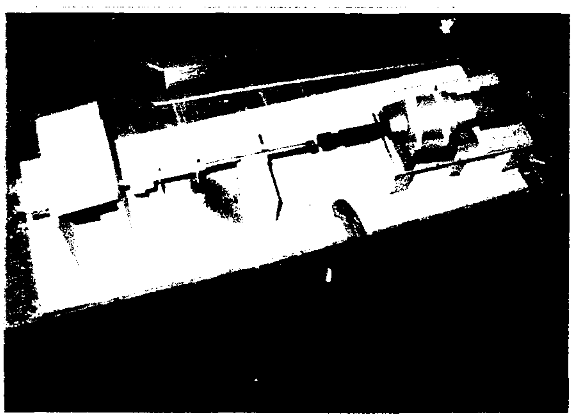


Figure 1. First Attempt at Automatic COILWINDER.

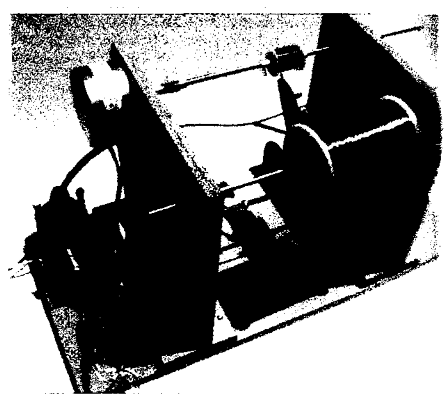


Figure 2. Final Completed Automat COILWINDER.

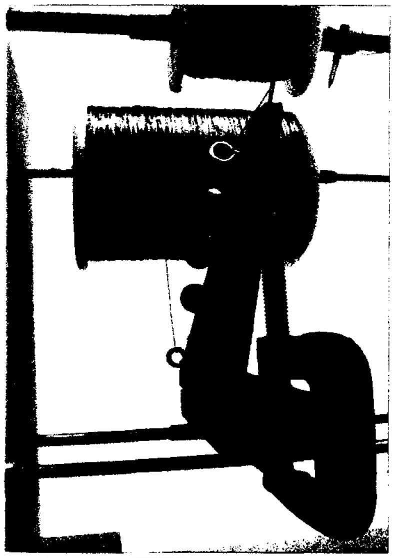


***Figure 3.* Finished Carriage.**

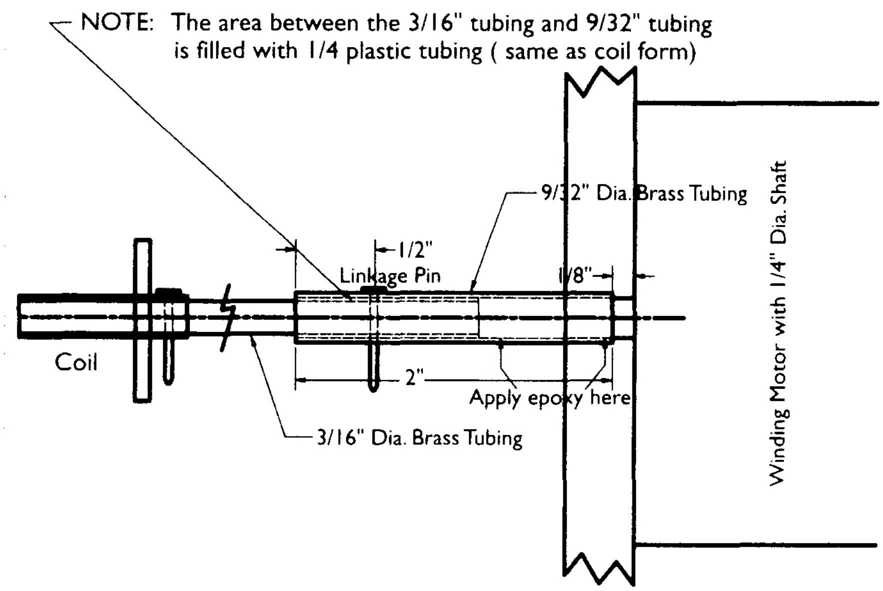


***Figure 4.* Detail of Shaft Coupling.**

..rrent flowing through a coil pro-..ces a magnet field which attracts ..ermanent magnet rotor which is connected to the shaft ..the motor. By trial-and-error grounding of the terminal ..ds while five volts was applied to the two center taps, .. proper sequence for clockwise rotation was found to RED, BLACK, BLUE, and WHITE. Reversing the ener-..ng order causes counter-clockwise rotation.

Two modes of motor operation are user selectable in .. software. The default mode is WAVE, which means that ..h of the four motor coils is energized one at a time, in ..uence. This mode draws minimum current. A second ..de is HI-TORQUE. In this mode, .. coils are energized at a time. This ..de requires twice the current of ..VE mode; however, it does pro-..e more torque in the motors.

I thought the COILWINDER would ..uire two stepper motors. One ..tor controls the rotation of the coil .. is called the winding motor. The ..ding motor turns the coil directly. .. other motor controls the move-..nt of a small carriage feeding the .. back and forth across the rotat-.. coil form. This motor is called the ..riage motor. The carriage motor ..es a lead screw which translates .. rotational motion of the motor to ..ear motion of the carriage.

Building the Hardware

The completed unit is shown in Figure 2. If you decide to use another stepper motor, just make the appropriate changes in the software for STEPANGLE and MAX_STEPS. If a threaded rod other than 32 TPI is used, change LEADSCREW_TPI appropriately. To drive the carriage, a "connector nut" for the leadscrew should be purchased or made. I made a connector nut from a one-inch piece of 9/32" square brass stock.

I drilled and tapped a #32 thread through the stock. Figure 3 shows that the carriage is made up of three pieces that are clamped together using a one-inch "C"

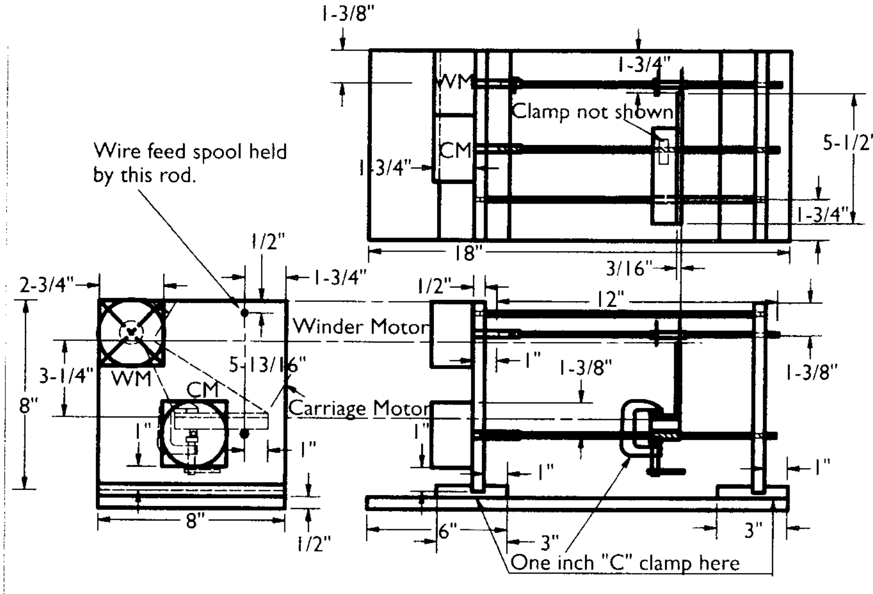


Figure 5. COILWINDER Drawing.

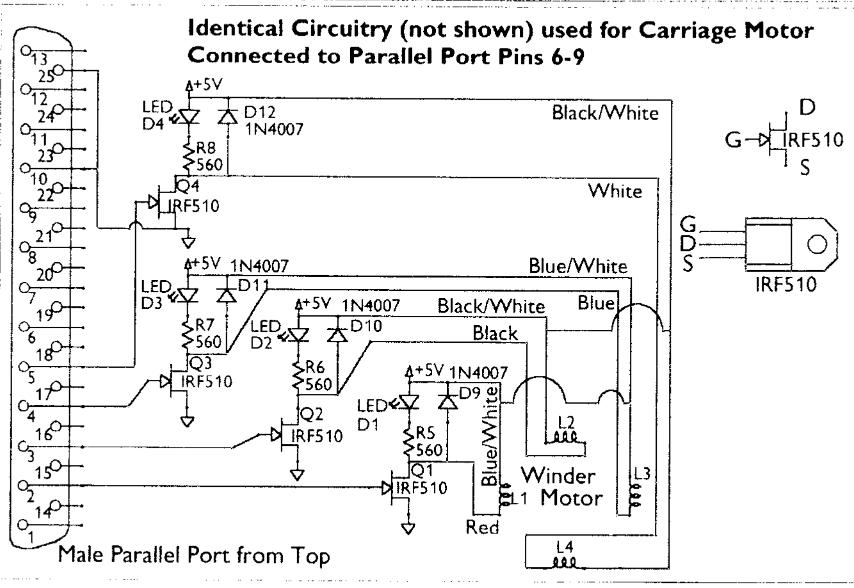
clamp: the connector nut, the carriage unit, and the wire feed unit. The reason for the clamp is to allow removal/adjustment of the carriage without the need to run the connector nut completely off the threaded rod. The joining of the leadscrew and winder rod to the stepper motors was done as shown in Figure 4.

The winder frame was built from 1/2" inch birch plywood. A detailed plan is shown in Figure 5. The assembly is straightforward, but the builder should be careful in drilling the holes for the motor shafts to ensure that they are parallel. The tensioning on the carriage pins are use increase the tension on the w ing spool. The number of tens ing pins used is dependent o wire gauge. The frame end ports are adjustable which sh allow for winding up to 11" co

The motor driver circuit is atively simple and was ini built on a breadboard, as show Figure 6. While the parallel does provide 0-5 volt signa does not provide enough cu to drive the motors. For this son, a separate power suppl needed for the motors. In the of five volt motors I chose, it five-volt power supply capabl supplying 2.8 amps at five vol you are using a stepper motor uses a different voltage, you r provide an adequate power sup

The circuit diagram is sh in Figure 7. Figure 8 shows the pinout for the PC par port. After testing on the breadboard, the driver ci was built on a 3 x 4 inch printed circuit board show Figure 9. Heatsinks were later added to the MOSFET keep them cool during extra long coil winds. The la of the circuit board is available at **www.nutsvolts.com**

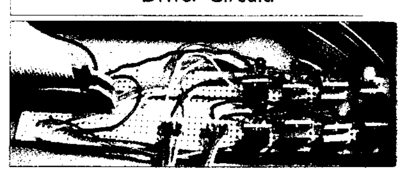
Figure 7. Circuit Diagram for Motor Driver.



Parallel Interface

Writing programs to talk with the PC parallel port pretty easy in the old DOS days in Win95/98, too. With the new er NT-clone operating systems like W NT4, WIN2000, and WINXP, all simplicity goes away. Trying to ru computer program accessing the p allel port on a WINXP computer give a "PRIVILEGED INSTRUCTI EXCEPTION" error message. Be relatively secure operating syste Windows NT/2000/XP assign so privileges and restrictions to differ types of programs. It classifies all programs into two categories: U

Figure 6. Completed Motor Driver Circuit.



ode and Kernel mode.

The programs that ers generally write fall o the user mode cate- ry which does not allow ect access to the paral- port. The workaround the above problem is write a kernel mode ver capable of reading d writing data to the rallel port and let the er mode program com- nicate with the driver. Fortunately, someone else has eady incorporated the driver into a dynamic link library lled INPOUT32.DLL, and it is available for free at **www.logix4u.net/inpout32.htm**

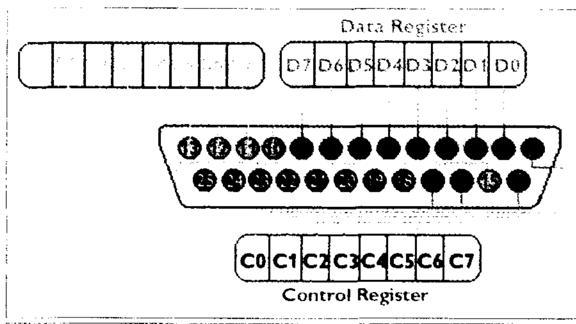


Figure 8. Parallel Port Pinout.

Figure 9. Printed Circuit Driver Board.

The outstanding feature of INPOUT32.DLL is that it rks with all the windows versions without any modification the user code or the DLL itself. The DLL will check the erating system version when functions are called, and if e operating system is WIN9X, the DLL will use INP and UT functions for reading/writing to the parallel port. On the her hand, if the operating system is WIN NT, 2000, or XP, vill install a kernel mode driver, HWINTERFACE.SYS, and k to the parallel port through that driver. The user code l not be aware of the OS version on which it is running.

The statements that make the parallel port input (INP) d output (OUT) functions available to the VB program are:

```
blic Declare Function INP Lib "inpout32.dll" _
as "Inp32" (ByVal PORTADDRESS As Integer) As Integer
blic Declare Sub OUT Lib "inpout32.dll" _
as "Out32" (ByVal PORTADDRESS As Integer, ByVal VALUE As
teger)
```

The DECLARE statements simply tell VB that the pro- ammer wants to use a function called OUT in his program at is known as Out32 in the INPOUT32.DLL located in the INDOWS/SYSTEM directory. The OUT function takes an gument called PORTADDRESS which is the address of the rallel port and an argument called VALUE which is the data be written to the parallel port. Program timing is controlled a call to the WINDOWS application programming interface EEP function using another DECLARE statement.

Designing the Software

The software was written in Visual Basic for an IBM ompatible PC and runs on all Windows operating sys- ms. The actual winding of the coil begins when the UILD COIL command button is pressed. For the actual nding of the coil software, I decided to use programming onsisting of "state machines." The use of state machines r each function enables the software to be small yet spond quickly to real-world events giving great precision to the motor control. Each function consists of a number of states. Each individual state requires only a few instructions to complete before passing program control to the next function. This process of breaking functions up into small states is a superior formalism for modeling dynamic real-time behavior. The program consists of four functions. Each function has multiple states, as shown in Table 1.

The functions are called sequentially and the states repeat the same actions until the state is changed. For example, once the winder motor is put into FORWARD state, it will continue winding on each execution until some new condition changes the state. Each state is a separate

Function	States				
PROCESS_ COMMANDS	GETSTART Allows user to manually position carriage to home position using L, R, P, and H keys	INITHOME Reads S or C key	STARTWIND Starts the winding process. Reads the P and T keys.		
CONTROL_ CARRIAGE	FORWARD Moves carriage motor one step forward	BACKWARD Moves carriage motor one step backward	PAUSE Output 0x00 to motors		
CONTROL_ WINDER	INITHOME Turns off winder and carriage motors	FORWARD Moves coil winder motor one revolution forward	PAUSE Calls CONTROL_ CARRIAGE if in JOGMODE otherwise output 0x00 to motors		
DISPLAY_ RESULTS	INIT Requests user to position carriage to home using L, R, and H keys.	HOMESTATUS Displays state of move to home	START Requests user to enter S to start, C to continue, P to pause, or T to terminate	WINDSTATUS Displays wind count and carriage steps from home	NOUPDATE Leaves current display unchanged

TABLE 1. Program Functions and States.

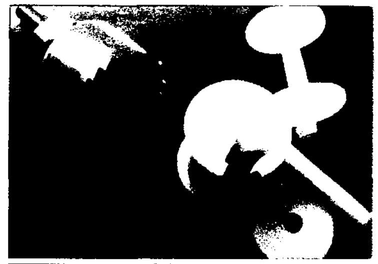


Figure 10. Coil Form Pieces and Too...

For the case of #32 mag... wire, we get:

Round(0.007951 inch /0.000... inches/thread) = Round(12.21) = Step... carriage motor = 12. = STEPSPERTUR...

CASE in the Visual Basic SELECT CASE statement. The CONTROL_CARRIAGE function is a sub-function of the CONTROL_WINDER function.

One of the key parameters in the program is INCH_PER_STEP. This parameter defines how far the carriage moves laterally on each step of the carriage motor. It is based on the steps per revolution of the carriage motor and the threads per inch of the carriage lead screw. For the motor and lead screw I chose, the STEPSPERREV=48 and the LEADSCREW_TPI=32. INCH_PER_STEP is calculated as follows:

INCH_PER_STEP = 1.000 / (LEADSCREW_TPI * STEPSPERREV) = 0.000651 inch per step

The main problem in the coil winder is determining how many revolutions the carriage motor should make per revolution of the winder motor. The value is calculated as follows:

One revolution of winder motor = WIRE_DIA = Steps of carriage motor * INCH_PER_STEP

Forty-eight steps are required for one revolution of t... winder motor, therefore an output step to the carria... motor should occur every four winder steps=STEP_RAT... If this is a non-integer value, it is rounded. In no case a... more carriage steps output than STEPSPERTURN p... winder revolution.

Since the coil winder is designed to wind coils w... multiple layers of windings, a second problem was to de... mine when the carriage motor should reverse directio... lay down the next layer of wire. This was accomplished ... using the SLIDESTEP counter and comparing it to t... maximum slidesteps per layer, MAX_SLIDESTEPS. F... example, for a one-inch coil using #32 magnet wire:

MAX_SLIDESTEPS = Int(WINDS_PER_LAYER *STEPSPERTURN... 1512

Where WINDS_PER_LAYER = Round(COIL_LENGT... WIRE_DIA) = Round(125.77)=126

In theory, the calculations above should result in a p...

Figure 11. Program User Interface.

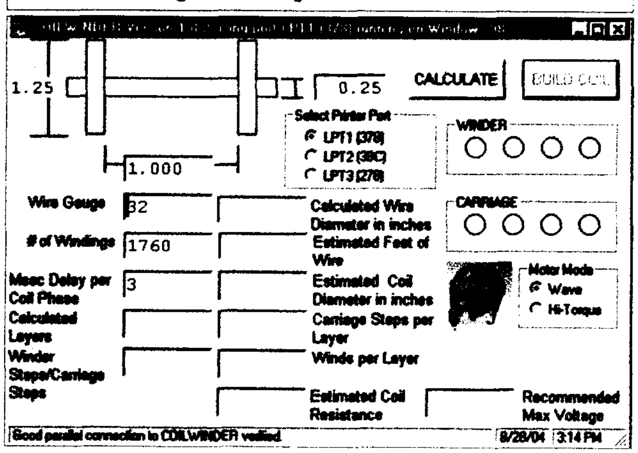
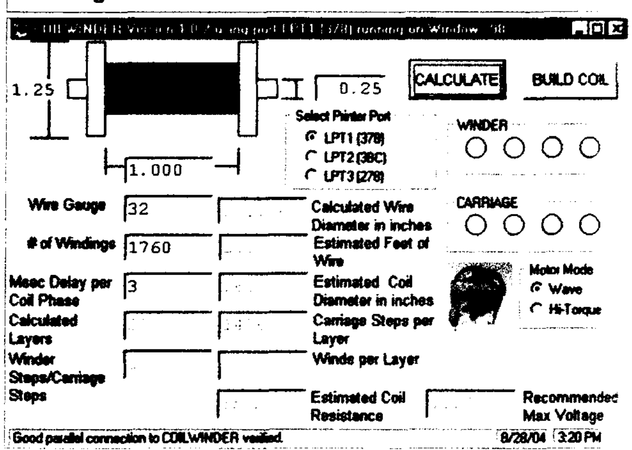


Figure 12. User Interface After CALCULATE Button.



coil. Unfortunately, the wire diameters in the code are based on wire gauges that do not include the insulation thickness. When I measured my #32 wire with insulation, I got a diameter of 0.01136 instead of the specified 0.0080. I modified the program to use the correct .01136 diameter for my #32 wire, but for other wire gauges, the user will have to modify the wire gauge/wire diameter lookup table after measuring their wire diameter with insulation. The VISUAL BASIC source code and installation package for the COILWINDER program are available from **www.nutsvolts.com**

Using the System

To wind a coil, first a coil form is needed. I built my spools from 1/4" styrene plastic tube and 0.06" thick sheet styrene, both available from your local hobby shop. I used a 1" hole cutter to cut out the round pieces of the coil spool. It also makes a nice 1/4" hole in the center for the tube. The spool end pieces are glued onto the plastic tubing with styrene plastic glue using an alignment tool fabricated from a thread spool. Small holes are drilled in the end piece for the wire feed and wire exit, and in the tube for the coil pin. The tools and pieces are shown in Figure 10.

The drive pin from the winder shaft is removed, freeing the winder shaft. The form is placed on the winder shaft and secured from free rotation with the coil pin. The winder shaft is reattached to the motor with the driver pin. Wire is fed from the supply spool, through the tensioning pins, through the needle's eye, onto the coil form, and out the coil feed hole. We are now ready to wind!

When the program is started, it first checks to see if the COILWINDER is connected to the parallel port. The user

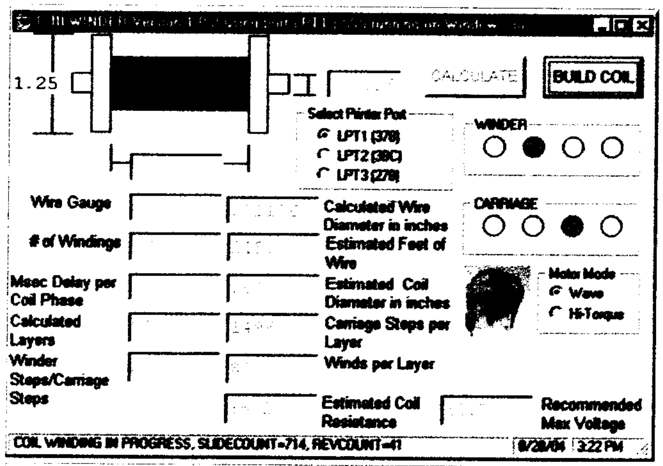


Figure 13. User Interface During Winding Process.

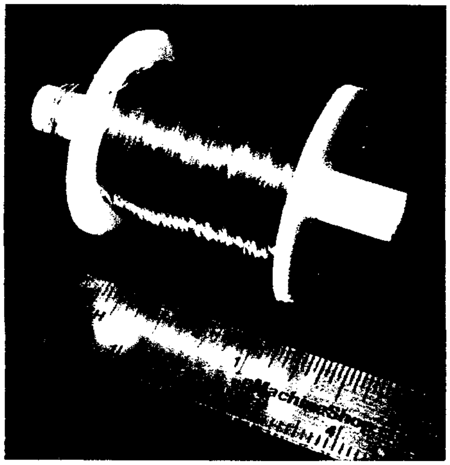


Figure 14. Completed Coil.

Sources and References

Source 1
Magnetic Gun Club
http://mgc314.home.comcast.net/index.htm

Source 2
Eddy Current Testing Information
www.ndted.org/EducationResources/CommunityCollege/EddyCurrents/cc_ec_index.htm

Source 3
Tesla coil design
www.noonco.com/tesla/

Source 4 — www.allelectronics.com

Source 5 — www.jameco.com

interface at program startup is shown in Figure 11. The user can enter wire gauge, coil diameter, coil length, the number of coil windings, and the winding delay. The user next presses the CALCULATE command button and the program calculates the estimated feet of wire required, the number of winding layers, the wire diameter, the outer diameter of the coil, and the number of carriage steps per layer.

Next, the program calculate the estimated coil resistance and recommended maximum voltag based on the resistance and the cu rent limit of the wire. The progra also calculates the ratio of wind steps to carriage steps using th equations above, as shown Figure 12. The number of feet ca culated is accurate to within abo 10%. The program recalculates t number of windings based on co plete wire layers. If you want t lead and exit wire to be on the sar end of the coil, make sure the nu ber of layers is even. For oppos ends, use an odd number of layer

When the BUILD_COIL co mand button is pressed, the STATUSBAR first instructs user to position the carriage to the "start winding" point using the "L" and "R" keys. The "H" key is used to indic that the carriage has reached home position. Next, the u is instructed to hit "S" to start winding the coil. When the key is hit, the winding starts and the STATUSBAR cont ously updates the carriage steps per layer and the num of windings completed, as shown in Figure The "T" key can be used to terminate the wind at any time. When the winding is complete, motors stop and the "L" and "R" keys are acti ed for initializing the next coil. During the wind process, the "P" key can be used to pause winding and the "C" key can be used to contin

In order to maximize the speed of the wi ing, whenever a motor is started, there is a step motor startup sequence where the first st takes ~221 times the input millisecond del The delay is reduced exponentially until 28th step takes the input millisecond delay. T was done to allow the motors to start up gra ally to prevent motor "chatter" that occurs w stepper motors are cycled at their maxim rate from a dead stop. If chatter still occurs the motors get up to speed, then the input lisecond delay should be increased.

Parts List and Suppliers

Quantity	Part ID	Description	Source/Part #	Cost	Total Cost
2	M1, M2	5 volt, 1.38 amp, 48 step/rev, 0.25" diameter x 1" shaft, Stepper motor	Source 6 SMT-62	$3.75	$7.50
1	T1	#10 x 32 threads per inch x 12" rod and connector nut	Source 8	$.96	$.96
3	BS1-3	3/16" x 12" diameter brass tubing	Source 9	$.75	$2.25
1	BL1	9/32" x 12" diameter brass tubing	Source 9	$1.19	$1.19
1	PT1	1/4" x 12" styrene plastic tubing	Source 9	$.75	$.75
1	PS1	.06" x 2" x 6" styrene plastic sheet	Source 9	$.75	$.75
8	Q1-Q8	N channel, 100V, 5.6 amp IRF510 MOSFET (#209234CL)	Source 7 209234CL	$.46	$3.68
1	DB1	DB-25 connector (male)	Source 7 15122CL	$.65	$.65
8	R1-R9	620 ohm, 1/4 watt resistor	Source 7 31376CL	$.01	$.09
8	D9-D16	1N4007 diode	Source 7 36011CL	$.04	$.32
8	D1-D8, D17	LEDs	Source 7 34606CL	$.15	$1.35
1	P1	5 volt/4 amp DC power supply	Source 6 15347-PS	$10.95	$10.95
1	SW1	SPST sub-miniature power switch	Source 7 72160CL	$1.29	$1.29
1	W1	1/2" x 18" x 8" birch plywood	Source 8		
2	W2-3	1/2" x 8" x 8" birch plywood	Source 8		
2	W3-4	1/2" x 3" x 8" birch plywood	Source 8		
1	W6	1/2" x 4" x 1.25" birch plywood (carriage base)	Source 8		
1	W7	3/16" x 4" x 8" birch plywood (wire guide)	Source 8		
1	BB1	Printed Circuit Board Materials or breadboard	Source 7		

Summing it Up

An interesting project of an automatic winder has been constructed for less than $35 The unit can automatically wind high quality c as shown in Figure 14. It took approximatel minutes to wind the 224 foot coil of # 32 ma wire consisting of 1,800 windings, using a d of three milliseconds. This project provides introduction to Visual Basic, the PC parallel and stepper motors.