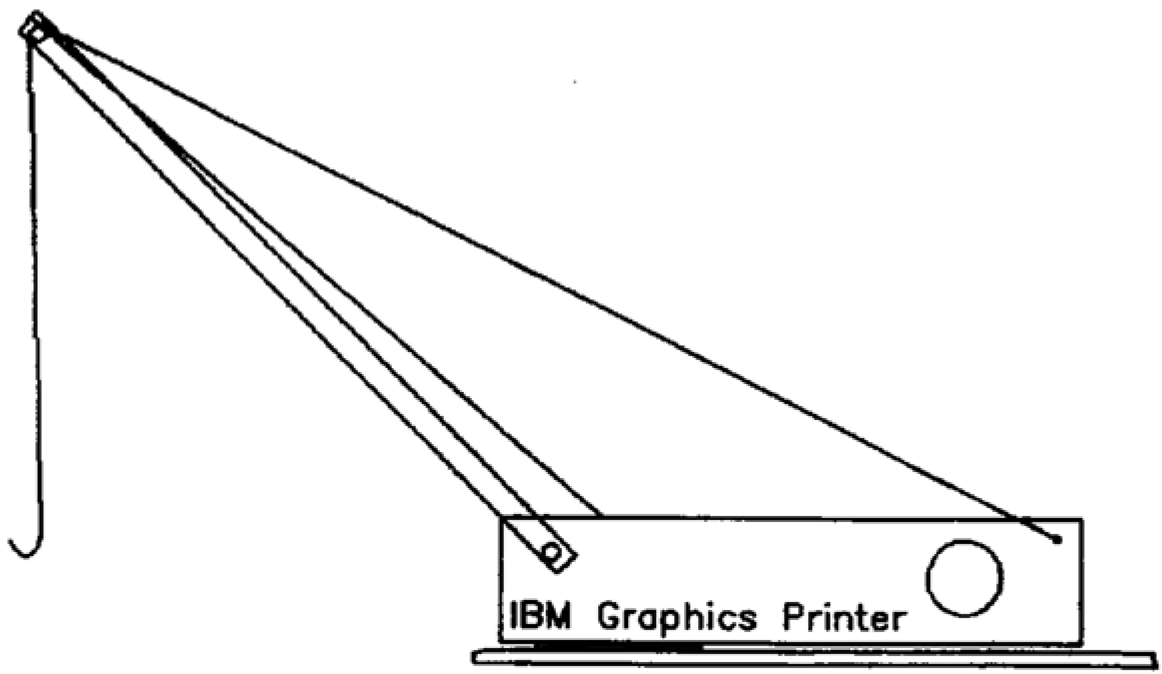
Computer Demolition Project 1: P.R.Crane
A PC Controlled Crane made from a Printer

"Will American kids be Inventors in 10 years, or just operate appliances designed elsewhere?"
and, by the way,
"Whatever happened to the Kid who took Alarm Clocks apart to discover how they worked?"



P.R.CRANE* is a *Computer Demolition Project* that creates a PC-Controlled Robot Crane.** You can control the crane manually with the arrow keys, have it learn a series of steps, and create and edit a robot control program. ***P.R.CRANE is made from an old IBM 5152 Graphics Printer, plus about $25 of parts available at the hardware store and Radio Shack. *Computer Demolition is based on the idea that you have to take technology apart to understand it.* The ***Computer Demolition Projects*** not only tell you how to take apart old computers, disk drives and printers, but tells how to *reuse* the many parts inside for innovative projects. So far, there are 3 *Computer Demolition* activities that have how-to manuals published free on our WebSite at: http:/homepages.together.net/~tking

- ***COMPUTER DEMOLITION I*:** is a class that starts by having kids[1] completely disassemble older Personal Computers, learn what the parts do, and then reassemble them and make them work They begin to understand the Technology of today by Taking It Apart**!**
- ***P.R.CRANE***: In this Manual
- ***D.D.TURTLE***: which is a simple tabletop robot made with 2 stepper motors and other parts from old 5-1/4" diskette drives. A LOGO-like control program is under development.

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[1]We use the term 'kids' pretty generically, including us adults who like to make things. *Computer Demolition* has been done with many Kindergarten to 2nd graders, Middle and High School students, and with Senior Citizens.

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P.R.CRANE

This is a project to build a computer-controlled crane out of an old IBM 5152 Graphics Printer[2]. It uses the original printer case as the 'cab' of the crane, and adds a 'boom' about 3 feet long that is bolted to it. A nylon cord wound around the Paper Advance shaft comes out of the 'cab', up through a pulley on the boom, and down to the working area. P.R. CRANE can lift about 5 pounds. The Up-Down movement of the crane cable is controlled by any old IBM compatible Personal Computer (worth $20 and up) with a printer port, and the software we supply. This type of printer is worth about $5 these days, but contains a wealth of reusable parts.[3] P.R.Crane utilizes the Paper Feed Motor to control a cable that can be moved UP / DOWN to lift and lower objects. Optionally, the Printhead Motor can be used to swivel the printer cab LEFT / RIGHT. A Boom, made of aluminum angle or wood strips, is attached to the 'cab' and has a pulley at the top that the cable runs through.

P.R.CRANE Construction:

Basic P.R.CRANE version:

The printer isn't actually changed very much in the basic version:

- 3 chips that are in sockets are removed
- 7 short wire jumpers are plugged into some of the socket holes.
- The original printer cable is used.
- A nylon string or cable is wrapped around the paper feed shaft. Only UP/DOWN motion is controlled.
- A metal or wood boom is bolted to the 'cab'

CRaneLanguage: UP <value> (up)   DN <value> (down)
Manual Control: Arrow Keys UP and DOWN

Going beyond the Basic P.R.CRANE:

If you're interested in doing more construction-type work, P.R. CRANE can be made into a version that can swivel around on a base, also under computer / motor control. An electromagnet can be made from a Radio Shack filament transformer and controlled by the computer. Then you can pick up iron/steel objects, and load or empty containers, trucks etc.. If you provide UP/DOWN and RIGHT/LEFT and MAGNET capability, the P.R.CRANE software will allow you to create robot control programs that you can edit and save. A favorite is a program that will loop around, picking up steel parts from a plastic dumptruck, lifting them, swiveling over to a 'factory' bin, and dropping them in. You can make the program loop (repeat) many times.

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[2]The EPSON MX-80 and MX-100 printers are essentially identical. We have only figured out the internal jumper wiring for the IBM 5152 because that's the one we have the schematic diagrams for. If anyone figures out another printer, or has the diagram for one and wants some help, please sent us an Email!

[3]See Appendix C for more information on the parts and subassemblies in these printers.

Here's a look at these options:

Swivel Base and Motor Control of Rotation:

CRaneLanguage: RT <value> (right)   LF <value> (left)
Manual Control: Arrow Keys RIGHT and LEFT

We want P.R.CRANE's Cab and Boom to be able to swivel around like a real crane does, to pick things up and them move them from side to side. To do this, we mount the 'cab' on a 'lazy susan' base, and have the original print-carriage motion motor swivel it back and forth. This requires a small base made of wood or particle board, a 'lazy susan' bearing available at many hardware or woodworking stores, and a short piece of nylon string and two small pulleys that run through the cab and are secured to the base on each side. We used a 6 inch bearing which costs about $4 at Home Depot. We used a white plastic-coated particle board shelf that was 1 foot by 4 feet and cost about $3 at the lumber yard. We cut the shelf in half to make a base about 12" by 24". The bearing was mounted with its center about 8 to 10 inches from one end.

(More details and Drawing To Be Done... We *need* a digital camera!!)

ElectroMagnet pickup and control:

The idea here is to add a controllable electromagnet that can be used on the crane cable. It can be controlled by the computer through the switching transistors originally used for the printhead magnets. We have made some strong electromagnets that work well on PRCRANE and can pick up fairly heavy things like a pair of pliers, a number of large nails at once, etc. We made our electromagnets from small transformers available at Radio Shack Pressing the <Insert> key turns the magnet ON and <Delete> turns it OFF.
CRaneLanguage: MG 1 (on) or MG 0 (off)
Manual Control: INSERT (on)   DELETE (off).

P.R.CRANE: Step-By-Step Instructions[4]

OK, if you're ready to start, here are our step-by-step instructions. If you find something confusing, or have a suggestion for a better technique or instruction, please drop us an Email at: tking@together.net

There 4 sections of these instructions:

1. **Basic P.R.CRANE:** Modification and testing of Motor controls. This is fairly simple, requires only 2 feet of hookup wire, and results in computer control of both motors, and a single UP/DOWN winch-like mode of operation.
2. **Electromagnet:** construction and installation. A fairly strong magnet can be used to pick up metal objects such as large nails and bolts, tin cans, tools etc. The magnet is under computer control and can be coordinated to automate moving metal objects.
3. **The Crane Boom:** Construction and installation. Results in a single axis UP/DOWN crane with computer control.
4. **Side-to-Side Swivel:** Construction and installation of the second axis of motion. This puts the crane on a lazy susan type swivel and adds a cable/pulley drive that allows computer control of this axis of movement using the printhead carriage motor.

Constructing The Basic P.R.CRANE

WHAT YOU'LL NEED:

- medium Phillips screwdriver
- small flat-blade screwdriver
- 3 feet of #22 solid hookup wire
- some kind of wire strippers / cutters. A knife *could* be used; careful!
- About 10 feet of strong Nylon Cord. In a hardware store this is often called #18 Mason Line. It is used by bricklayers and other construction workers to line up parts of buildings.

First, make sure your printer basically works. Put a piece of paper in (even if you can't find that old perforated paper). Hold down the LINEFEED button while you turn the power switch on. The printer should start in test mode and try to print character test lines. Don't worry about the print quality (or even if you have a ribbon!). As long as the printer runs, and the paper advance knob moves, and the printhead carriage moves back & forth, it's alive. If you get a series of beeps, there's no paper in position.

1. Also, with the ONLINE button / light OFF, you should be able to push the LINEFEED button and have the paper advance knob move, and the FORMFEED button and have the knob turn

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[4]Where to get one??? This was the printer IBM sold with the original PC and XT. The EPSON MX-80 is basically identical. They cost about $5 at computer flea markets and 'hamfests'. Check with people at your local 'Ham Radio' club, 'Computer Users Group', or used computer dealers to find out where the flea markets and scroungers are.

about 4 times. The microcomputer controlling the printers paper feed says it only goes up, not backwards. (We'll see about *that* later!)

2. Pull the black paper advance knob firmly straight out and remove it.
3. Remove the hinged top cover section. Remove the metal wire paper guide, if it's present, by pushing the ends towards the center where they plug into the case.
4. Unplug the printer and turn it over.
5. In the 4 corners you will see recessed phillips-head screws. Unscrew all 4 until they are free. Turn the printer right side up. The 4 screws should fall out of their recessed holes. Save them.
6. Lift the top carefully straight up, then towards the paper advance shaft on the right.. The control panel wiring will still be attached. Notice that it plugs onto the control panel. Unplug it, noting the way it goes on.
7. Remove 2 Phillips head screws holding the control panel in place on the cover, and separate it from the cover.
8. Plug the control panel cable back into the control panel, and push the black paper advance knob back on its shaft. Now the printer is workable again, minus the cover. If your printer has had a particularly tough and dusty life, this is a good time to blow or vacuum it out.
9. If the printer was intact and printed previously, this is a good time to get a good look at how it works inside. Go back to section 1, above, and try it out. Perhaps connect it to a computer and print some interesting stuff.
10. This is also a great time to use the printer as a series of examples of how electronics and electromechanical devices are designed, and what construction methods and materials are used. NOTE: We have a detailed discussion on this subject in Appendix D. If it's appropriate to your class or use of this material, go to Appendix D now.
11. OK, this printer has printed its last page. Remove the Printhead: (1) Move the printhead to it's rightmost position and follow its flat strip cable down to the printhead connector. Pull the flat strip by it's stiff end section, to the right and out. (2) Note the small metal lever on the left front of the printhead. Push it to the left as far as possible and then lift the printhead upward and remove it. Push the level back to it's original position. It is spring-loaded, so use a bit of masking or duct tape to hold it in place so it won't catch on things.
12. Try running self-test (Hold down front most button and turn on power). Push a small piece of paper in the paper feed slot on the left side, covering the gold-colored paper-out switch. You'll get a good view of how the printer *used* to work! The printhead carriage should go back and forth, and the paper knob should advance after each move.
13. Now to the Fun Stuff: Rewiring the Printer. First, take a few minutes and look from the front at all the parts of the printer. Notice the power cable, switch and power supply components such as the transformer (labeled MD80UA) in the right rear of the printer. Notice the main circuit board in the rear center and left. Notice the small motor driver board atop the main board in the left rear section, with a large blue connector on top, and rows of black plastic power transistors. See all the good stuff you got for 5 bucks with this great, though aged, printer???
14. Notice that the small motor driver board is held down with two Phillips head screws along the left side of the printer. Remove these screws and save them. Unplug the large blue connector from the top of the driver board. Notice the driver board is still plugged into the main board by small black connectors on the edge towards the middle. Carefully, keeping the board level

so that it unplugs straight up, pull upwards and wiggle the board free. Put it temporarily aside.

15. Look carefully at the main circuit board, from the front of the printer so the writing is right side up. Notice a few things:
16. The rightmost section is the power supply, with a transformer and 3 large cylindrical filter capacitors.
17. In the left rear is the printer cable connector that goes to the PC.
18. In the center area are two 'DIP' switches. There are sockets (probably empty) for optional character sets. Note that each chip has a location label, like 1A, 2A, 3A, 1B, 1C etc..
19. In the left rear area are the connectors (labeled CN4 and CN5) that the driver board plugs onto. Also note the two large 40 pin chips that are plugged into sockets in the area that was covered up by the driver board. They are labeled 9B and 8B. Next, we will locate and remove 3 of the chips.
20. Close to the leftmost edge there is a 40pin chip at location 9B. It is an 8041 Microcomputer[5] which is connected to all of the motor controls and stubbornly thinks it owns them. It has to let go for us to take over. Using a small flat-blade screwdriver, pry it up out of its socket at one end, about 1/8". Do the same at the other end. Try to keep it coming up flat without twisting. Alternate ends until it is free and you can lift it out. Save as a souvenir. NOTE: If the center black strip of the socket pulls up out of position, reposition it and push it back down.
21. Next to the newly-empty socket is another 40-pin chip at location 8B. It is an Input/Output chip that is connected to the printer cable coming from the PC and thinks it is the only one that is allowed to talk with the PC. Shut it up forever by prying it up and out...
22. Finally, over in the center section, partially under the printer mechanism, in apartment 1C, is *another* Microcomputer. It is an 8049, and you know how bossy *they* can be. It's outta there. You may have a little difficulty prying the edge under the mechanism. You can pry the free end up about 1/4" and then push it back down, then up again. Eventually you'll work it loose.
23. Now we have an attractive, but lonely, set of motors with no previous committments, and a printer cable with umteen signals and nobody to talk to. We just need to connect them up directly and then we can control the motors from the PC's printer port in any way we want, without any opinionated Microcomputers telling us what we can do and what we can't do. Since all the connections are on socket pins that we can push a wire into, it won't be too hard.

    Look closely at the two 40-pin sockets at locations 8B and 9B that you just removed chips from. Looking from the front of the printer, note that the socket at 8B has small numbers around it. The lower right corner is the starting point, pin 1. Going up the right side there are numbers printed at 1, 5, 10, 15, and 20. Pin 20 is the upper right. The upper left is pin 21, and the number system continues down the left side to pin 40 on the bottom left. (Sockets 9B and 1C are numbered the same as this). Pin numbering on Integrated Circuits (IC's) always goes this way: *Counterclockwise from the top*.[6]

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[5]A Microcomputer is a single-chip computer that has it's program and configuration permanently embedded on it's chip. They are inexpensive in large quantities, but in most cases no changes to them can be made. Microcomputers (Often called Microcontrollers these days) are used to control many modern devices like VCR's, Microwave ovens and Automobile engines. You will have two of them for conversation pieces or paperweights after you make a P.R.CRANE

[6]IC numbering originated from Vacuum Tube socket numbering, which is *Clockwise from the*

Find your piece of #22 solid hookup wire. (This is a good size to push into sockets made for chips.) #24 (slightly thinner) would be OK. Stranded wire (made up of several tiny strands) will not work; it will not plug into the sockets well. You can get this wire at Radio Shack (Catalog Number 278-1215 or 278-1221) or Email us a request and we'll send you a piece if you're on a tight budget! Cut 8 pieces 2" long. Carefully strip the insulation about 3/16" at each end of each piece.

Refer to the two columns on the right side of the table below. Place wires at the locations shown. To plug a wire into a socket pin, carefully point the bare wire end straight down into the socket, and push it straight down. If it bends, reposition it and try again. You may want to hold the wire with small pliers. Make sure most of the bare wire end is going down into the socket, and doesn't touch the bare wire next to it. After a wire is plugged in on both ends, bend it down towards the left rear and down flat against the sockets. *Note*: This table also tells us what the wires are connected *TO*, but you can ignore that for right now.

Printer Port Out Bit	Function	WIRE FROM Socket 8B	TO Socket 9B
0	Printhead (Left/Right) Motor Magnet 1	pin 21	pin 27
1	Printhead (Left/Right) Motor Magnet 2	pin 22	pin 28
2	Printhead (Left/Right) Motor -ENABLE	pin 23	pin 29
3	Printhead (Left/Right) Motor +HI / - LO	pin 24	pin 30
4	PaperFeed (Up/Down) Motor Magnet 1	pin 25	pin 31
5	PaperFeed (Up/Down) Motor Magnet 2	pin 26	pin 32
6	PaperFeed (Up/Down) Motor -ENABLE	pin 27	pin 33
7	ElectroMagnet (Printhead #1) +ON	8B pin 28	8B pin 36

24. Double-check that your wires are in the right socket pins and that no bare wires are touching each other. Now, replace the Motor Driver Board by carefully aligning it on the black pins at CN4 and CN5 and pushing it straight down. Plug the blue connector back on the top.
25. BEFORE plugging the printer power cord in, read the ***CAUTION***[7] below:
26. Read over the following sections on Hardware and Software to get a feel for what's going on and how this all works.
27. Install[8] the PRCRTEST.EXE and PRCRANE.EXE programs on the PC[9] you're using.

Bottom (where you wired the tubes from). Same as Counterclockwise from the Top!

[7]***CAUTION*****:** You have to be careful to have the P.R.CRANE motors controlled properly whenever the printer Power switch is turned on, or they will overheat! Originally the Microcomputers inside the printer (remember them??) took care of this. Now, we have to be responsible for this, every time the computer and printer are first turned on. We give you a software program called CRANEOFF.EXE that you should run every time the computer is rebooted. You can put it in AUTOEXEC.BAT so you won't have to remember it. NOTE: the printer is OK if it's power switch is OFF, and any time you run PRCRANE. CRANEOFF is because you just MIGHT forget! (Don't ask me why I know!)

[8]If you're not familiar with loading programs and running them in DOS, ask someone for help.

28. Decide which printer port on the computer you will use. You have to tell the PRCRANE software the name of the one you're using. You may have only one, especially on an older machine. Carefully look at the back of your computer where the cable from the display plugs in. Near the display cable connector should be some other similar ones. You are looking for a 25-pin connector with two rows of holes: one row with 12 holes and one with 13 holes. Your printer cable should fit it easily and plug in. If you have only one such connector, it is likely that it is called LPT1. If you have two such connectors, you will need to identify which one is which. A second printer port will typically be known as LPT2. [10]
29. You must tell your computer which printer port the PRCRANE software should use. You do this by typing a command at the DOS prompt, like this: `SET PARPORT=LPT1`
Use "LPT1" or "LPT2" or "LPTM" in this command depending on which printer port you are using. NOTE: You should put this command as a line in your AUTOEXEC.BAT file so that you don't have to remember and do it manually each time you start up your computer.
30. Connect a standard printer cable[11] between the PC you will be using and the printer. Make sure the printer power switch is off , then plug the printer power cable in.
31. Get ready to Run PRCRTEST and see how you're doing! We suggest these steps:
    - Before you turn the printer power switch on:
        1. Rotate the manual paper advance knob now, with the power off. It should turn pretty easily. Get used to how hard it is to turn. Use just your thumb and forefinger.
        2. Move the printhead (or printhead carriage if you've removed the printhead already) manually to the center of it's travel. Notice how hard it is to move the printhead with the power off. It should move pretty easily. You should just notice a little 'cogging' or bumpiness to the movement. These are the steps that the magnets in the motors pass through.
        3. Start up PRCRTEST by typing "prcrtest" at the DOS prompt. This will make sure the printer port bits are set up to run P.R.CRANE.
    - Turning the power on:
        1. Turn the printer power switch on. (It is best to leave the power switch on for about 1 minute at a time, with a 3 or 4 minute rest in between, until you are sure the motors are running OK and the wiring is right).

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[9]While you're scrounging about for a Graphics Printer, you're bound to see a lot of old computers. Grab an old XT or AT (about free) or an older working 386 (about $25 to $100), (or two) and dedicate them to running projects like P.R.CRANE. Keep an eye out for an original IBM XT (Front says "IBM Personal Computer XT", back says "IBM 5160", you say "I'll give you five bucks.."). XT's are best for 'Computer Demolition' (Get our Manual!).
[10]If you have an old PC or XT with a "monochrome display and printer adapter" it is known as "LPTM" to the PRCRANE software. LPTM is also used if you have an IBM PS/2 computer with a built-in printer port.
[11]P.R.CRANE has problems with stiff, heavy printer cables when it swivels left and right. Try to find a cheap 'modern' printer cable that is thin and flexible.

2. Manually move the printhead sideways a little. It should be harder than with the power off, but still fairly easy to move. You should notice very pronounced ‘steps’ in the movement. If the printhead is *very* hard to move, turn the power switch off and troubleshoot.[12]
3. Manually move the paper knob, with just thumb and forefinger. It should also be harder to turn, but not a lot. If it’s *very* hard to move, power off and troubleshoot.
4. If this part seems OK, continue to run PRCRTEST

32. Running PRCRTEST: We suggest the following steps. First, a few tips on running PRCRTEST:
    - Each test is displayed in order. You then have four choices, which you pick by pressing a single letter on the keyboard:
        - ❖ R Runs the test. After the test is done, you will be back at the same point, and you can Run the test over again if you wish, by pressing “R” again.
        - ❖ N Goes to the Next test. It will display it’s number and description, as the first test did. Again, you can Press “R” to run it, or rerun it.
        - ❖ B Goes Back to the previous test without Running the current test. So you can press “N” for Next or “B” for Back several times to skip up and down to get to whatever test you want. Tests only Run when you press “R”
        - ❖ Q Quits the PRCRTEST program immediately and goes back to the DOS prompt.
    - TEST 1: Takes 10 motor steps UP on the paper feed motor, and 10 steps DOWN. You should hear the 10 steps, and if you watch the paper feed wheels closely you should see them move very slowly for a short distance.
    - TEST 2: Moves the paper feed motor UP part of a turn (about 1 tooth of the paper feed sprockets) fairly quickly, and DOWN the same amount even faster.
    - TEST 3: Moves the Printhead Motor 10 steps slowly RIGHT, then 10 LEFT more slowly.
    - TEST 4: Moves the Printhead Motor RIGHT medium speed, LEFT faster. (Make sure the printhead carriage is in the center of its travel before going to the next tests).
    - TEST 5: Is a multifunction Demonstration that runs each motor at 4 different speeds over larger travels.
33. You may want to run the P.R.CRANE software at this point, even if you intend to go on and add the boom, magnet and swivel base. You can run the motors with the arrow keys, and try a few things out. But real Robot Crane programs will require the magnet and swivel axis movement to be really interesting.

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[12]**TROUBLESHOOTING (1) :** If the printhead or paper knob are *very* hard to move as soon as the power is turned on: Go to APPENDIX E: TROUBLESHOOTING (1)

Constructing The Electromagnet:

P.R.CRANE is much more useful and fun with a good electromagnet. Robot Crane programs can be easily written that repeat operations such as picking up metal objects at one location and dropping them in another. You can unload a dumptruck full of nails into a container, for example.

The electromagnet we suggest is made from an easily-available Radio Shack filament transformer that costs $3.99. Of course, we take it apart and make it into something *ELSE!* The electromagnet is controlled by the computer through one of the transistor drivers that originally drove a printhead magnet. A step-by-step procedure for wiring up the electromagnet to the crane circuit is provided below.

Our magnet is made by loosening and then removing the iron laminations of the transformer, which are about 40 thin strips of metal shaped like "E" and like "I". The strips are originally stacked together with the "E" and "I" shapes *alternating* to form a shape like a squared off "8". After removing and separating all the laminations, we discard the "I" shaped ones and restack all the "E" shapes back into the transformer winding bobbin. The open end of the "E" goes down and is the active magnetic pickup area. The original transformer primary winding is suitable to be driven by the 24V DC that was used in the printhead. The magnet draws 2 watts.

Electromagnet Construction:

WHAT YOU'LL NEED:

- Radio Shack Catalog # 273-1385B filament transformer
- Leather work gloves
- Sturdy knife (A 'utility knife' is OK)
- A small flat-blade screwdriver
- A small hammer
- A vise or a wood block with a slot cut in it. What is needed is a small slot that the transformer can be placed over, to allow the first lamination to be forced downward.
- Access to an oven (*Not* a microwave oven)
- 18" of #22 solid hookup wire
- 36" of flexible twisted-pair wire
- Duct Tape and Masking Tape

Step-By-Step

1. Use the leather work gloves when working on the transformer, either hot or cold! Examine the transformer closely. It has a metal frame surrounding it with two mounting feet with holes in them. Next to the mounting feet are two bent-over tabs holding the frame in place. Unbend and straighten them, using the small screwdriver, and knife if needed. Across between the holes is a separate metal strip. Pry it up and out of position. Now push the feet with the holes

in them apart, and remove the metal frame from the core of the transformer. Discard the two frame parts.

2. Examine the transformer's dark metal core closely. Looking at the edge, you'll see it is made up of many thin layers of metal. (They are called *laminations*). There are two shapes of laminations: one shape like a squared-off "E", the other like an "I". They are alternated in the stack to produce a shape like a squared-off "8". The center like of the "8" goes through the center of the transformer wire windings. The laminations are stacked tightly, and also have been dipped in varnish, which makes them hard to separate, but it CAN be done!
3. Hold the transformer so the connection pins are down and the writing is right side up. Look at one side and then the other. Notice that the outermost laminations are "E" shaped, with the "E" on its side facing up or down. Look for the edge of the "E" section, and notice it stops before the edge. Notice that on one side the "E" faces UP and on the other it faces DOWN and its edge is nearer the connection pins. Look at the writing on this side of the transformer and write it down so we won't forget it.
4. Put the transformer on the rack of an oven and set the oven to 200 degrees F (100C). Let the transformer heat up for at least 10 or 15 minutes. This will soften the varnish so we can more easily take it apart. Ready your leather gloves, vise or wood block, thin-blade flat screwdriver, knife and hammer.
5. Using gloves, remove the heated transformer from the oven. It will retain heat for 5 minutes or more. Position the transformer so you can see the side you marked, above. Find the end of the "E" shape on the side of the core, near the connection pins. Carefully use the knife to push between the outermost lamination and those below it. Once it is loosened, work your way around the transformer core, loosening that one lamination all the way around, down to the other end.
6. Now the hard part: getting that first lamination to move! Place the transformer upside down with the loosened lamination over the slot in the vise or wood block. You will push down on the center of the "E" lamination with the thin-bladed screwdriver. Look at the center of the transformer core, just at the edge of the stack, for the EDGE of the center leg of the "E", right in the center, next to the white plastic winding bobbin. Carefully position the flat screwdriver blade straight down so it meets the EDGE of the center part of the lamination squarely.
7. Holding the screwdriver in this position accurately, hit the screwdriver moderately with the hammer. You need to force the "E" lamination downward, to separate from the stack. Once it moves, you can grab it with pliers at the TOP of the transformer, and pull it upward and free.
8. Now, you've uncovered another "E" in the opposite direction, with a small "I" ant its end. Use the knife to separate the "I". It should come off easily. Now loosen the "E" as you did before. Hopefully you can pry it free enough to pull it out without too much difficulty.
9. Now, it's a repetitive job of using the knife to separate and pry loose a lamination: "I" then "E", and removing them. You'll end up with a pile of "E" and "I" shapes.
10. When all the laminations are removed, it's a easy job to select all the "E" shapes and stack them all in the winding bobbin, FROM the end with the connection pins. The finished electromagnet will be used with the writing upside down, the connection pins up, and the "E" laminations all pointing downward. You will see 3 'poles' which are the 3 ends of the "E" laminations. Think of the "E" shape as two "U" horseshoe magnets side by side.

11. The magnet needs a lifting attachment. Using the 3/32 bit, drill two holes carefully through the edges of the while plastic winding bobbin, in the center between each set of two connection pins. Drill from the inside out, at a very flat angle, with the drill bit ending up almost hitting the laminations. Thread a small piece of nylon string, or wire, through the two holes, and fashion a lifting ring.
12. Strip 3/8" of insulation from one end of the twisted pair wire. Locate the connection pins labeled 120V 60HZ. Twist the wires carefully around the connection pins. Solder these if at all possible. If not, twist the wire near the white plastic, and bend the connection pin in a "U" shape around it. Tape well with masking tape.

You're done! What a job, but a great electromagnet is the result.

We plan to offer a finished electromagnet as an available product for about $20 in about April of 1999.

Electromagnet Wiring:

Your job here is to wire the magnet to the printhead connections, securely.

WHAT YOU'LL NEED:

- 2 - 9" pieces of #22 solid hookup wire
- 3 - 1" by 2" pieces of duct tape

Step-By-Step

1. Notice the printhead connector in the center of the area where the carriage runs right and left. Look at it from the extreme right and you'll see that it has 12 connector sockets. We number them 1 to 12 from the rear to the front. Next, you'll make the connecting wire section.
2. Cut 2 - 9" pieces of #22 solid hookup wire. Strip 3/8" from each end. Twist the wires together at a point about 1-1/2" from one end. Make about 6 tight twists at this point and keep about 1-1/2" untwisted. Now continue towards the far end, twisting the wires together more loosely now, to about 1-1/2" from that end.
3. At the first end, bend each stripped wire back on itself so the bare end is shaped like a "J" about 3/16" long. Use pliers to squish the "J" together so the two parts of the wire are right next to each other and you have a flattened end.
4. Move the printhead carriage to its leftmost position. Straighten your wire assembly and position it beneath the carriage drive belts, coming towards the printhead connector, from right to left. Push one flattened, doubled wire end into printhead connector socket 3 and the other into socket 6 (counting from back/right). Flatten the wire assembly neatly along the bottom.
5. Notice that there is a small slot in the metal frame near the right front end of the round rod the carriage rides on (Just to the right of the Epsom nameplate). Feed the free end of the wires through that slot, towards the front of the unit, and again flatten the wires neatly against the bottom. Cut 3 pieces of duct tape 1" by 2". Center one lengthwise over the wiring, starting

about 1/2” from the printhead connector. Press firmly in place. Place another piece over the right section of wire.

6. Position the bare ends of your wires pointing towards the front and upward.
7. Get the magnet, and strip 1/2” from the ends of its wire. Pass this end rearward under the right end of the metal bar, and then forward through the same slot the other wires are going through, from back to front. Pull a few inches through. Tie a figure “8” knot about 1 1/2” from the end, tighten it. Pull the wire back until the knot stops it.
8. Align the wire ends, and carefully twist one magnet wire to one hookup wire, then the other ones. Position the twisted sections along the inside of the plastic case about 1/2” apart. Cover with another piece of duct tape, and press securely in place.
9. Cut a 2 1/2” piece of hookup wire and strip 3/8” from each end. On the motor driver board, locate the rear end of R6 (near Q19) at the back edge of the board. Carefully pass one wire end under the rear end of R6, and make a second loop through. Squeeze this connection securely. Route the other end across to the vertical pin labeled T0. Wrap the wire end securely around the pin and squeeze in place. (If at all possible, solder these connections).

You’re done with the Electromagnet and wiring!

Constructing The Crane Boom:

WHAT YOU'LL NEED:

- Access to a hack saw, metal file and electric drill or drywall gun type drill. Access to a vise to hold and bend the boom pieces.
- 3/32" and 3/16" twist drill bits. You'll be drilling plastic and aluminum.
- 2 - 24" pieces of Boom Material. One of the best is angle aluminum that is 1/2" by 1/2" and 1/16 (.062)" thick. Available in larger hardware / lumber outlets.
- 2 - Two large sheet metal screws to attach the boom ends to the crane body. #12 screws that are 1/2" long are best. Up to 1" long is OK.
- 1 - small pulley for the boom top. These are sometimes called "awning pulleys" and are for small (1/8") cord.
- 3 - #6 by 3/8" sheet metal screws for the "Boom Cable" attachments at the rear of the crane body.
- 4 - feet of the same strong Nylon Cord previously specified, to support the boom.

Step-By-Step: You will cut boom material, drill holes, bend each piece as needed, drill holes in the crane body, modify the pulley, and assemble the boom and supporting cables.

1. Cut two 24" pieces of the boom material. Use a file to remove sharp edges caused by cutting.
2. Note how the boom pieces will be arranged: a flat side against each side of the crane body, and a flat side on top.
3. Mark 1/2" from each end, where the booms will meet the crane body, and join at the top.
4. Drill 3/16" holes at each end, centered about 3/16" from the open edge.
5. Decide which boom part is left and right, mark them for positioning.
6. Mark the end of the boom pieces that will attach to the crane body at 1-5/8" and 2".
7. NOW, refer to figure ?? and clamp the end of a boom piece in the vise, at the 2" mark. You may want to cut a small template at the 70 degree angle in figure ??
8. Holding the boom piece near the vise, force it to bend in the correct direction. This will be *stretching* the top flat part. Check the angle. When you're part way, loosen and reclamp the piece in the vise at the 1-5/8" mark. Bend some more. You may want to carefully apply a wooden or plastic mallet to help the bend, or hold a wood block and hit it with a hammer. Stop when you're at about the correct angle. Then do the opposite piece, the other way.
9. Mark the unbent ends of the pieces at 1" and 1-3/8" . Clamp one in the vise at 1 3/8". These will be harder, as the top flat part is being *compressed* and will probably ripple up or down as the piece is bent.
10. Bend these pieces the correct amount. Again, after getting part way, loosen and reclamp at the 1" mark. If the top edge ripples a lot you may want to use a hammer to flatten it somewhat.
11. Now, mark the Crane body (Uh, printer top case) as follows:
    - At top front of both sides, for boom attachment: 1-1/4" down and 1-1/4" in from front. Make a starter place with a center punch or medium nail and hammer at each mark. Drill 3/16 holes.
    - At top back of both sides, for sheet metal screws for boom cable attachment: 3/8" down and 3/8" from back. On left side only, mark at 2" down, 3/8" from back. Make starter

places. Carefully drill three 3/32” holes only 1/4” deep. Put a bit of masking tape on the drill bit to show where 1/4” is.

12. Reinstall the control panel into the top case, being careful to get the LED’s aligned properly into their holes. Make sure it positions OK, then attach with the original two screws .
13. Reinstall the top case. When it’s in position, turn the printer upside down, keeping it in place. Reinstall the 4 screws in the 4 corners to attach it. Turn the printer right side up.
14. Screw 3 - #6 by 3/8” sheet metal screws into the 3 holes at the top rear of the cover. Screw them in only 3/16”, leaving 3/16” exposed to hold the boom support cables.
15. Position the boom sections in front of the crane body, and line them up with the two 3/16” holes in the front sides. Screw in 2 - #12 by 1/2” sheet metal screws, through the boom sections into the case. Don’t quite completely tighten them, so the boom moves fairly freely.
16. Install the boom pulley, that also holds the boom together at the top:
    - Modify the pulley so it can be bolted in place:
        - ❖ Remove the riveted pin that holds the rotating sheaf: Note the riveted end, clamp the pulley body in the vise, and use the metal file to file off the end of the rivet until it is flush with the pulley body. Use a small nail or punch to drive/hammer the pin out of the body and release the rotating sheaf.
        - ❖ While the pulley body is in the vise, carefully drill the hole out a bit with the 3/16” drill. Then carefully clamp the rotating sheaf in the vise, and drill it out to 3/16”.
    - Insert the 10-32 cap screw through one side of the boom, the pulley body, the sheaf positioned in the pulley body, and through the other side of the boom. Install a lockwasher and nut. Position the pulley body so that the original attachment eye points straight back, and tighten securely.
17. Install a piece of the strong nylon string as the boom support cable:
    - Prepare one end by heating with a match to seal the end so it won’t ravel. Tie a slipknot close to the end. Tie it around the single sheet metal screw at the right rear. Tighten.
    - With the boom almost straight out from the body, figure the length of string to go through the pulley attachment eye and back to the left side screws. Cut the string with another match, applying a slight pull, and sealing the end. Route the string through the pulley attachment eye (not the sheaf) and then tie another slip knot in the end and attach to the top sheet metal screw.
    - Lift the boom up to 45 degrees or more, and wind the boom support cable around the two sheet metal screws at the left rear, ending with the string going forward over the top screw. Lower the boom so it is supported by the string. The boom angle can be adjusted by the number of turns on the screws.
18. Install a 5 to 6 foot piece of the strong string as the crane lifting cable:
    - Prepare the ends with heat. Attach the string around the square paper advance shaft near the right end. Best is to tie a ‘clove hitch’ AKA ‘two half hitches’ around the shaft, followed by two more half hitches on the line. Else use the good ‘ole slipknot.
    - Route the string up through the rotating pulley sheaf and straight down. Attach a cool hook on the end.

Try lifting Stuff!! Get a few interesting objects like wrenches, coffee mugs, doughnuts and others that have holes your hook can hook. Run the P.R.CRANE software and experiment with lifting different weights at different speeds. A two quart plastic milk/juice bottle full of water is about 4 pounds and is a good maximum load test. Note that the crane may fail to lift this weight unless the speed is 200 steps/sec or less. If you built the electromagnet, now's the time to hang it on the hook and try it out!

Constructing the Side-to-Side Axis:

NOTE: Before you go on to "Constructing the Side-To-Side Axis", it's best to temporarily remove the boom by removing the two large sheet metal screws and the cables. You will need to turn the printer over from right side up to upside down a bunch of times, and the boom will be *very* much in the way.

P.R.CRANE needs to be able to swivel from side to side like a real crane does, to pick up objects in one place and put them in another place. We will put our crane body on a "lazy susan" type bearing so it can swivel, and add a cable arrangement that will allow the side-to-side motion of the printhead carriage to instead make the crane swivel side-to-side.

WHAT YOU'LL NEED:

- Access to an electric drill or drywall gun type drill.
- A 12" by 18" approximate size base, of wood, plywood or particle board material. A typical 12" by 36" shelf cut in half is good. Cheap shelves covered with a plastic coating are widely available.
- A 6" size "Lazy Susan" bearing, available in most hardware and lumber stores.
- 4 - #6 by 3/8" sheet metal screws
- 4 - #6 by 1" sheet metal screws. These can NOT be longer than 1".
- 2 - small pulleys. These can be the same type used for the boom top, or can be made from nylon spacers and fender washers available at most hardware stores.
- 2 - 24" pieces of the strong nylon string.
- 4 - small (3/16" shank) metal eyelets such as those used as shoelace eyelets. Available at most sewing supply stores and many hardware stores. The 'installation tool' used to crimp them into clothing is NOT needed.
- A small amount of epoxy glue.

Step-By-Step: You will mount the "lazy susan" bearing between the Crane cab and wooden base[13]. You will glue eyelets in two holes in the cab, and mount two pulleys on the base and run string cables and attach them to the printhead carriage.

1. First, with the printer right side up, identify the two holes that will have eyelets installed in them: Move the printhead carriage to the center of its travel. Look down at the rear drive belt that drives it, and look left about 3" to find a hole in the bottom of the printer that is a little over 3/16" in size. Look 3" to the right of the carriage for another such hole. These are the holes that will have eyelets glued in them at the top and bottom so that the 'cable drive' strings will move freely, like a shoelace in an eyelet.
2. Install bottom eyelets: The left hole will probably have a label stuck over it on the bottom of the printer. Turn the printer upside down, and cut the label about 1" around the hole, and peel that part off, so that the bottom eyelet will have a good place to attach. Drill the two

[13]You might wonder "How can the flat bearing be installed, when there's no room to get at it to put in screws??" In a minute, you'll see the trick.

holes bigger using your 3/16" bit. Clean any chips out of the holes. Mix a small amount of epoxy glue (or use SuperGlue). Put glue lightly on the outer barrel of an eyelet and the underside of the top lip. Carefully put the eyelet in the hole and press it down in position. Do the same for the second bottom eyelet. Wait long enough for the epoxy to set up well, and then turn the printer right side up.

3. Mix another small amount of epoxy and insert the top two eyelets. You need to reach down past the drive belt, and keep from getting epoxy on it or in the hole. You can hold the eyelet with needle-nose pliers or a tweezers if available, or make a small wood stick, tapered to hold the eyelet while you position it. Wait for these eyelets to set up also. Then turn the printer upside down again.
4. Install 'cable drive' strings: Cut two pieces of the strong nylon string 3 feet long, and heat-seal the ends. You will tie each string to a ventilation slot in the printer bottom. Make sure the front of the printer is towards you. To the left of the left eyelet about 1 1/2" there are 8 horizontal slots. Route a string down through the rear (top) slot and up through the next slot. This is hard, so strip about 1" of insulation off a piece of your #22 hookup wire and bend the end into a tiny hook. "Fish" through the second slot to pull the string up through. Tie a slip knot about 1/2" from the end of the string, and tighten and pull it to the right. Likewise, look to the right of the right eyelet and notice 5 vertical slots. Tie the other string down through the rightmost slot and back up the next slot. Tighten and pull towards the rear.
5. Decide which type of rear cable pulleys you will use. IF you will use assembled "awning pulleys" like the one used for the boom top pulley, pass a string through each pulley now and temporarily tape it to the side of the printer.
6. Pass the free end of each string up through its hole and pull all the slack through. Temporarily coil the strings up around the drive belts inside.
7. Make sure the printers front is towards you. Make a mark on the printer base from side to side, 3/8" back from the front edge and parallel to it.
8. Examine the "lazy susan" bearing and assure that it turns freely. Notice that the bearing has two different sides with different hole patterns. Placed the side with the 4 individual 1/8" holes downward against the printer base.
9. Note the pattern of ribs in the plastic printer base. There are 6 from front to back and 2 from side to side.
10. Carefully place the bearing with its front edge on your mark. The back edge should be just atop the rear horizontal rib in the base. Line up the back of the bearing with the back of the rib, exactly. Center the bearing side to side. Hold the bearing carefully in position, and reach through the holes with a small marker to mark the hole positions. Remove the bearing.
11. Make starter points on each mark, with a center punch or medium nail and a small hammer.
12. Carefully drill 3/32" holes at each mark. NOTE: The two holes towards the rear will go through the plastic and hit the internal metal base. Stop drilling as soon as you go through the plastic. Put the printer aside and get the wood shelf base.
13. Decide which surface of the wood base will be up and mark a light pencil line 3" from the front edge. Notice that the other opposite side of the "lazy susan" bearing has 8 holes, 4 large and 4 small. Place that side down, with the front edge centered along the marked line. Carefully mark straight down through the *SMALL* holes.
14. Make starter points on each mark, with punch / nail.
15. Carefully drill 3/16" holes straight down through the base.

16. If you have access to a countersink, you can use flathead screws that end up flush with the bottom. In that case, countersink the *bottom* side of the holes you just drilled, just enough to have the screws flush. Otherwise use roundhead or pan-head #6 by 1” sheet metal screws. In that case, the screws might later scratch a tabletop, so add rubber feet to the bottom of the base. NOTE: In either case, try putting the screws up through the holes. They should protrude only about 3/16”, so they will not hit the other side of the bearing later.
17. Assemble: Place the bearing in position on the upside down printer. Install #6 by 3/8” sheet metal screws through the 4 individual holes in the bearing, into the 3/32” holes you drilled into the printer. Tighten *very* lightly, just enough to take up the slack. Do not tighten enough to bend the bearing.
18. Place the 12” by 18” wooden base upside-down on the “lazy susan” bearing. 4 - #6 by 1” sheet metal screws will go down through the holes in the base and into the 4 *small* holes in the bearing. The screws go in only 3 or 4 turns. It’s hard to line up the first one. Screw it in only loosely, then align the opposite screw and hole and tighten it loosely. Install the other 2 screws. Tighten all screws lightly, just so there is no slack between the bearing and the base. The wooden base should rotate freely. If it hits something or drags, look for a screw that went up through the base too far, and is hitting the opposite side of the bearing. If necessary, remove a screw and put a small round washer under its head to increase the clearance.
19. Turn the unit back right side up, and check how easily it rotates on the bearing.
20. Next, you’ll install the cable drive system that uses the printhead carriage motion to swivel the crane body left and right. Cables will go from the printhead carriage inside, across and down through the eyelets, rearward to the back edge of the wooden base and around pulleys there, and back to the attachment points where you already tied the cables.
21. Install the rear cable pulleys, depending on which type you decided to use:
    - “Awning Pulleys”: These should be untaped and the string freed and the inside of the end of the string tied or taped inside so it can’t escape! The pulleys are attached with two #6 by 3/8” sheet metal screws into two 3/32” holes drilled about 1/2” from the rear of the wooden base, and centered evenly , 8” apart. Depending on the pulley type, you may need to tie the pulley ‘eye’ to the sheet metal screw with a very short piece of wire or nylon string. The pulleys must end up *horizontally*.
    - “Nylon Spacer and Fender Washer Pulleys”: These are installed on two #6 by 1” sheet metal screws. Place a fender washer (large washer with small center hole) on the sheet metal screw, followed by the nylon spacer and a second fender washer. Screw this assembly into 3/32” holes located 1” from the rear of the wooden base and centered evenly, 8” apart. Tighten just enough to keep the washers from being loose without binding on the nylon spacer.
22. Route the cables from the eyelets, back to the inner side of the pulleys, outward around the pulleys and back to the attachment points you already made. Center the crane cab on the base, and temporarily wedge it in place.
23. Note the two small Phillips head screws atop the printhead carriage. Temporarily remove them, along with the two thin metal pieces they held.
24. Pass both string ends UP through the rectangular hole in the center of the carriage. Use your wire hook to “Fish” them up through. Route the strings towards the rear, between the screw holes. Reposition the larger metal piece over the strings and start the small screws back into their holes. Route the strings outward and forward so they are grabbed under the metal.

25. Center the printhead carriage, and make sure the crane cab is centered and the cables are routed through the pulleys properly. Pull the strings through to just take up the slack, without making them at all tight. Lightly tighten the screws on the carriage to hold them in place. If the strings are much too long, cut and heat seal them with a match to about 2".
26. Unblock the crane cab so it can swivel freely. It's time to run the P.R.CRANE software and try it out!

NOTE: The rear of the crane cab has both the power cable and the printer data cable coming out of it. If these cables drag appreciably they will stall the side-to-side movement as the printhead motor does not have much power. Arrange the cables so they are free and have a half loop of slack near the cab. If there is plenty of room behind the crane, arrange them loosely straight back, with a loop of slack. If the crane is atop a system unit or desktop, you may have to arrange the cables to have a half-turn of slack and hold them in place with masking tape.

Running the PRCRANE Software:

The P.R.CRANE software comes in one "ZIP" file that comes from our website. A "ZIP" file is a 'package' than is easy to ship around the Web, and contains several things inside it. See Appendix F for more information on this. Running your P.R.CRANE is basically simple: just push the arrow keys on the keyboard for UP or DOWN, RIGHT or LEFT. Pushing another button like the END key above the arrows, or the Ins/0 key just to the right of the arrows will stop the move.

To control HOW FAR each move is, and HOW FAST, look at the upper right section on the screen below. The *Speed* of moves means "How many steps *per second* will the motor take?". 10 steps per second is pretty slow. 100 steps per second is pretty fast[14] The *Size* of moves means "How many steps *Total* will the motor take?" You can change the values on the screen by pushing the + or - keys on the upper right of your keyboard, or the PageUp and PageDown buttons.. You will see that one of the 4 values in the box is highlighted, and changes with + and -. You select which value to change by pushing the * and / keys OR the Home and End keys to move the highlighted bar. Try it out...

The P.R.CRANE screen looks like this:

```
|-------------------------------------------------|--------------------------|
|Help|Load|Quit|Edit|Run |Stop|Step|Brk |Learn|Save|P.R.CRANE                 |
| F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9  | F10|(c)1999 Mountain ClockWork|
|-------------------------------------------------|--------------------------|
|   trylearn.crl                                  | UD  500 STEPS/SEC        |
|   1  UD      490                                | UD 2000 STEPS/MOVE       |
|   2  RL       60                                | RL   62 STEPS/SEC        |
|   3  DN     4000                                | RL   50 STEPS/MOVE       |
|   4  MG     1                                   |--------------------------|
```

[14]Stepper motors like those in P.R.CRANE have a problem running at a few special speeds where they resonate or vibrate strongly. At these speeds the motors will jump around erratically. If you see this behavior, try a slow speed, like 40 Steps/Sec, to make sure the motors work OK, then see what speeds (usually between 70 and 100 Steps/Sec) are a problem, and "Don't Do That!" Higher speeds up to 200 Steps/Sec on the RT/LF and 500 Steps/Sec on the UP/DN are usually OK.

```
|   5  WA      2000                                |                          |
|   6  UP      7500                                |--------------------------|
|   7  RL        20                                |                          |
|   8  RT       200                                |--------------------------|
|   9  UP       500                                | PROGRAM: STOPPED         |
|  10  WA      2500                                |--------------------------|
|  11  MG      0                                   |                          |
|  12  RL        60                                |--------------------------|
|  13  LF       200                                |                          |
|  14  DN      4000                                |--------------------------|
|  15  LP         5                                |                          |
|  16  ST                                          |--------------------------|
|  17  ST                                          |                          |
|-------------|------------------------------------|-------|------------------|
|StepNow =   1| PgmDesc: Learn Mode Produced Program       |                  |
|-------------|--------------------------------------------|------------------|
```

After you have enough fun running P.R.CRANE manually, you'll want to try out robot programming. The P.R.CRANE software includes a robot crane control language we decided to call CRL (Crane Language). Why Not?? CRL is much like simple LOGO except the directions are different. You can create a CRL program in two ways:
(1) LEARN MODE: You push F9 to start 'learning'. Then you use the arrow keys to move and the <Insert> and <Delete> keys to turn the magnet ON and OFF. Each move is automatically added to your CRL program. When you are done with the sequence you want P.R.CRANE to learn, push F9 again. Next, push F10 and give your program a name, to save it. To RUN your program, push F5. To STEP through your program one move at a time, use F7. To EDIT your program, push F4.[15]

F KEY Functions:

The P.R.CRANE software displays the functions the F Keys provide at the top of the screen:

F1	HELP	A short reminder of how PRCRANE works, and CRL commands.
F2	LOAD	Asks for the name of a saved CRL program. Loads and displays it.
F3	QUIT	You must confirm with "Y"
F4	EDIT	Loads an external Text Editor, which edits the current CRL Program. When the editor ends, the program is reloaded and displayed.
F5	RUN	Starts the CRL program at the current step (usually beginning)
F6	STOP	Stops a running CRL program after the current step finishes
F7	STEP	Runs ONE CRL program step, and stops at the next one.
F8	BRK	"BREAK" quits looping after the current program gets to the end.
F9	LEARN	Starts or Ends LEARN MODE in which arrow key moves are saved.
F10	SAVE	Save the current CRL program on disk. You may provide a new name, or enter "=" for the same as current name.

CRL Robot Programming Commands:

[15]You must provide a simple text editor such as E.EXE or EDIT.EXE from DOS. (We will try to find one we can include). To make your editor work, you MUST set the EDITOR variable in the 'environment'. You can do this at the DOS prompt by typing
SET EDITOR=C:\DOS\EDIT.EXE or whatever the complete path location of your editor is.
NOTE: You should put this same command in your AUTOEXEC.BAT so you won't forget it.

The CRL commands you can use are these, created in LEARN MODE:

UP <steps>	{Goes UP 10 times the number of steps. 100 here is about an inch.)}
DN <steps>	{ Same for DOWN}
RT <steps>	{ Goes RIGHT the number of steps. 100 here is about 10 degrees.}
LF <steps>	{ Same for LEFT}

In EDIT, you can also add these additional CRL commands:

UD <Steps/Sec>	{ Sets the Steps/Second Speed for UP/DN moves }
RL <Steps/Sec>	{ Sets the Steps/Second Speed for RT/LF moves }
WA <1/100 Sec>	{ Waits for 1/100 of a second for each value here}
ST <0>	{ STOPS the program where it is. You can push F5 or F7 to continue }
LP <value>	{ LOOPS (Repeats) the program a number of times. Then it ends. }

NOTES: Other functions you may need:

<Alt>N	{ Pushing this key combination clears the CRL program, creates a blank program named NEWPGM.CRL which you can save (F10) with a new name.} Handy for a new LEARN Mode try.
<Alt>D	{ Pushing this combination lets you type in the Program Description which is saved with your program and appears when you LOAD it (F2).
<Alt>R	{ RESETS your program step to the beginning. Use this if you STOP your program and want to start over at the beginning.

P.R.CRANE HARDWARE AND SOFTWARE

First, A Look at the Hardware

P.R. CRANE is going to be a *Computer-Controlled* crane. This means that the motors and other electrical parts will be controlled by a computer, by turning *Bits* On and Off.[16] Some motors can only be turned On and Off, like the starter motor in a car. Other motors can have their speed changed, like a mixer or blender or Variable-Speed electric drill. Still other motors are made to take precise steps instead of just spinning. They are called ***Stepper Motors***. The two motors in the 5152 Graphics Printer (the Paper Feed Motor and the Print Head Motor) are Stepper Motors. Originally the two Microcomputer chips in the printer controlled them. Now it's our job! Let's look briefly at how Stepper Motors work.

Stepper Motors are very suited to computer control because they work by switching the magnetic windings inside them On or Off. (...sounds like *BITS* to me!) There are *two* sets of magnets in these motors. Each magnet can be magnetized in *two* ways: (usually called North and South). Think about it. *Two* magnets, and each can be magnetized *two* ways, so there are *four* different combinations of magnets. Our Stepper Motors have a pattern of *four steps* that they take. We will call them steps A, B, C, and D so we won't get confused with numbers. Remember, there are four possible combinations. We can call them A,B,C,D or we can call them by the magnet combinations: NN NS SS SN. Each of our two magnets is controlled by its own Bit. If the Bit is 0 or OFF the magnet is magnetized in the North direction. If the bit is 1 or ON the magnet is magnetized in the South direction. So, lets look at these combinations:

STEP	MAGNET 1	MAGNET 2	BIT: MAGNET 1	BIT: MAGNET 2
A	N	N	0	0
B	N	S	0	1
C	S	S	1	1
D	S	N	1	0

OK, look at this for a minute. There seems to be a pattern or rule about how the magnets change direction. Can you see it?[17]

Notice that the Bits are assigned this way: 0 means North, 1 Means South. Because of the 'only one changes' rule, the bits go in the pattern 00 01 11 10 . [18] If we connect two bits in our PC to the motors (through the Motor Drivers), we can make the motors step in this pattern!

---

[16]Remember that Bits can only be 0 (ON) or 1 (OFF). Appendix B Has a short course (unfinished) that we're working on about "Bits&Bytes" and what they're all about.
[17]The rule is 'both magnets can't change at once'. To go from one step to the next step, only one magnet changes direction.
[18]Buzzword: A bit code where only one bit changes at a time is called a 'gray code'.

Direction Control

Now, how do we go around and around?? How do we go *backwards*?? Look at it this way-- the pattern repeats indefinitely: ABCDABCDABCDABCD etc.. etc.. Now, if you stop on step C and want to back up, how do you do it?? Just make the next step B, then A, then D, etc.. You can stop anywhere, and go either way next. Got it?? The *step next to A is D* ! Like this:

```
          A
     D         B
          C
```

So, you can go around Clockwise ABCDABCDABCD
or you can go Counter Clockwise ADCBADCBADCB

Our motors take more than 4 steps to go around once, but they just repeat the pattern over and over as they go around.

Now you see why Stepper Motors are so cool! All a computer has to do to make them step and run forward and backward is to control 2 bits in the right pattern. As an example, ABCDABC is the bit pattern 00 01 10 11 00 01 10. All our computer has to do is flip the right bits On and Off. We'll do that in *software*.

Speed Control

Ok, we can Start, go in either direction, and Stop. But *how fast are we going*? What controls that?? What matters is: *how long is it between steps?* Think about it. If we wait a long time between steps, the motor will run slowly, like step ------- step ------- step ------- step. But if we wait just a short time between steps, the motor will run fast, like step-step-step-step. Computers are good at doing things fast, and timing things accurately, so they'll be good at this. We will put a Delay between steps. If the Delay is long, the motor will run slow. If the Delay is short, the motor will run fast. How fast can we go?? Our motors can go as fast as 500 steps in one second. We just have to control the Delay properly. We'll do that in *software*.

Oh, Yeah?? WHAT software?

OK, here's the deal. We give you some software that we have written, that can control a P.R. CRANE that is built pretty much like ours was, as well as some test software to make sure your rewiring works, and some general purpose bit test software. Here's what we have:

<u>PRCRANE.EXE</u> Controls The UP/DOWN and RIGHT/LEFT motors and an Electromagnet to pick stuff up with. The arrow keys on the keyboard start motors moving for UP/DOWN/LEFT/RIGHT . F keys let you pick 1 of 4 speeds . Other keys let you set how many steps each 'move' is. The screen shows what speeds and move sizes you have set. We include the source code in Turbo Pascal so you can see how things were done, and expand the software to do new functions.

PRCRTEST.EXE Is intended for initial check-out of a P.R. Crane. It has some preset tests to check things out. You can Run or Loop (Repeat) each test, skip back and forth to different tests, etc. It also displays the bits for the input devices such as control panel buttons, that you may have optionally wired up. You could also use it for testing other devices that you build using the printer as a starting point.

SEEBITS.EXE (See appendix C) is a general-purpose full screen program that shows you 8 bits coming in from the printer Port on your PC, and lets you set the 8 output bits as you wish.

Caution: If you use SeeBits on a printer that is powered up, make sure you know what the Output Bits Do!! Make sure you don't turn the printer motors ON on High Power and leave them on! You can burn them out if they're left full on for several minutes. PRCRANE.EXE won't let you do that! In SeeBits, first turn all bits ON (you can just push the S key for *SET*). Note that most of the bits on P.R.CRANE are active when Low (0)!

APPENDIX A: GLOSSARY

Printed Circuit Board:
Switch:
LED (Light-Emitting Diode):
Resistor:
Connector:

APPENDIX B: Bits N' Bytes

Bits N' Bytes :An Exploration In Electricity and Computer Science

We are working on a major educational unit called Bits N' Bytes. Our teaching materials are not yet finished and published. We hope the preliminary materials here will help out for the moment.

Bits N' Bytes is designed as a hands-on activity for Elementary and Middle school kids in which they explore and learn about *"Those Bits that everyone knows are inside computers"*.

Although Bits N' Bytes is intended to be a classroom unit that takes place over 8 to 12 sessions, the material has also been used to develop an introductory one session presentation suitable for use in National Engineers Week and other outreach activities.

Bits N' Bytes is best done as a very hands-on activity, in which ***BITS*** that come out of a PC's Printer Port are connected to LEDs that light up, or other **Output Devices**. Switches and other **Input Devices** are connected to the Printer Port and their ***BITS*** appear on the computer screen. We provide free software on the World Wide Web:

Bits N' Bytes Software:

From http://homepages.together.net/~tking/parport.htm

SeeBits: Is a PC Program that let's you see and control bits. SeeBits is a Fullscreen program for Control and Monitoring of Parallel Port Bits. It has large 'Bits' on its screen that can be seen across a classroom. SeeBits uses a "Printer Port" (often called a "Parallel Port"). SeeBits runs under DOS (Or in a DOS session in Windows) on any IBM-compatible computer. OLD XT or AT type machines are good, cost about $20 these days, and you can dedicate one to controlling projects, equipment or your home.

SeeBits is the simplest, beginning software to use to start. ALL it does is allow you to turn 8 OUTPUT bits ON and OFF, and display the state (ON or OFF) of 8 INPUT Bits. Later, you may want to SEQUENCE things, and perform LOGIC to be able to make decisions. For this you will need to write software of your own, or use a Sequencing program such as BitMach which is included in our free software package.

OUTPUT PORT: SeeBits uses output bits of a printer port for OUTPUTS to control External devices such as LED lights, beepers, relays or transistors. Pins 2 through 9 on the printer port connector are used. The BIT numbers and PIN numbers may both be seen on the SeeBits screen.

INPUT PORT: SeeBits uses bits from two funny input ports on the printer port and "fixes and unscrambles" them so that Pins 10 through 17 on the printer port connector appear as 8 available bits. NOTE: Bits 1 and 2 often "float" down (ON) if just simple switches are used.

OUTPUT CONNECTIONS are from Pins 2 through 9 to GROUND (Use any Pin 18 through 25 for Ground).

INPUT CONNECTIONS are from pins 10 through 17 to GROUND (Use any pin 18 through 25 for Ground).

Bits N' Bytes: We've got the Questions; You find the Answers!

Everybody knows that computers run on BITS. And there's LOTS of them in there!

BUT:

* What are bits LIKE?
* What do they DO?
* How do bits get IN to the computer, and where do they come OUT?
* How can we get bits to come OUT of the computer where we can see them and play with them?
* How many kinds of bits ARE there?
* What do bits MEAN?
* What does it mean when you have more than one bit at a time?
* What can we tell bits to DO??
* What does the computer DO with bits, anyway?
* If we have TWO bits, what does AND mean? OR? NOT?
* What things do we see and use every day that are LIKE bits?
* How are switches and lights like bits? Your house Thermostat?
* What are LEDs? (Light Emitting Diodes). What makes them light up?
* Where do we hook up wires to the computer to get bits to come out and light up LEDs?
* Where do we hook up wires to the computer so our switches will become bits?
* What are the SYMBOLS for Switches, and Lights? Draw a DIAGRAM of what you are hooking up.
* How can we hook up switches to make AND? How about OR?
* What's a MATHEMATICAL operation? What's a LOGICAL operation? What do they look like if we write them down on paper?
* If we make GROUPS of bits, how big should a usual group be? What would the NAME of that kind of group be?
* Can we use all the bits in a group as individuals?
* The bits we are using were made to usually go to the printer and print characters and words and lines and pages. How can a group of bits tell the printer what character to print?
* What bits have to be ON and OFF to make the letter "A"? How about "a"?
* What is the BYTE that tells the printer to go to a new line?
* Write down the BYTES that make up your name. Put them into the computer. Make the computer send them to the printer, or to the display.
* How do we use bits differently to make NUMBER VALUES instead of CHARACTERS?
* What is the BYTE that equals ZERO? ONE? TWO? FOUR? THREE?
* What SET does each column (BIT) in a BYTE stand for?
* What is the LARGEST number you can have with 8 bits?
* Make the byte for 8. Then one for 11. Show how to ADD them.

* Now, use bits as individuals for OUTPUTS. Hook up more than one light. Hook up some OTHER things that can be ON or OFF, like beepers, or magnets with flags, or butterfly wings, or motors.
* The bits coming out of the computer are not strong enough to run more powerful actuators like motors, electromagnets and MuscleWires. Hook up a TRANSISTOR to a bit that you need to be more powerful.
* Hook up some OTHER things that can be INPUTS. Like special switches that are SENSORS.
* What PHYSICAL QUANTITIES in your classroom can you think of to sense? TEMPERATURE? LIGHT? AIR FLOW? PRESSURE? WEIGHT? With one bit can you tell HOW MUCH? Or just MORE OR LESS?
* Explore how to write PROGRAM statements that tell the computer what INPUT BITS to look at, how to DECIDE what to do, and what OUTPUT bits to turn on. Make the computer turn ON "your" light when "your" switch is ON.
* Tell the computer to blink your light on and off quickly. How do you tell it HOW LONG AT TIME to turn it on? How do you tell time for short time less than one second? What do you call 1/1000 of a second? A MILLIONTH?
* Explore how to tell the computer to do one thing after another after another in SEQUENCE.
* DESIGN some strange device or machine. Make it out of cardboard etc.. Put switches, lights, sensors or actuators on it. Wire them up as INPUTS and OUTPUTS. Write a computer program that looks at the INPUTS, makes DECISIONS, decides the SEQUENCE of things, and turns the OUTPUTS on and off. Try it out. It probably won't work right the first time, so DEBUG it.

Materials and Prerequisites:

1. An IBM type Personal Computer, with a regular parallel printer port card.
2. Some wire, LED's (Light Emitting Diodes), switches, sensors, beepers etc.
   (Less than $25 at Radio Shack) [TBD: Part Numbers!!]
3. (Optional) A Cable Breakout Board (makes it easy to get at the bits).
4. (Optional) More and Better SENSORS and ACTUATORS, such as Motors, Thermostats, Electromagnets, MuscleWires(tm) etc..
5. ParPort software (Freeware) from **http://homepages.together.net/~tking/parport.htm**
6. The BITS 'N BYTES Guidebook (We hope! We're trying to get time and money/resources to write this well.)

Learners should have previously done the computer activity called "Computer Demolition" in which they completely disassemble and reassemble an IBM XT type computer. This can done concurrently.

APPENDIX C: Parts and Subassemblies in the 5152 Printer

The IBM 5152 “Graphics Printer” was sold with the original PC and XT. It is a “Dot Matrix” printer originally made by Epson with some design and reliability updates by IBM. One *major* advantage of this printer is that IBM *published the schematic diagrams* in the IBM PC Technical Reference Manual!! This means you can find out exactly how it is wired!

Major Subassemblies:[19]

Power Supply: Provides +12, +24 and +5 volts.

Electronics Assembly with cable to a PC printer port. This can be easily rewired to give direct PC control of the motors in the printer.

Motor Driver Sub Assembly with power transistors and cabling to the motors discussed below. Also contains 9 power transistors originally used to fire the printhead magnets, that can be rewired to drive other devices under computer control, such as an Electromagnet or lights.

Stepper Motor Assembly with gear reduction: This is the original Paper Feed assembly. The Gear reduction drives a 3/8” square shaft and cogged paper advance wheels. If a cable or nylon cord is wrapped around the small square shaft, there is enough mechanical advantage to lift 5 pounds. This may also be used with two cables to provide a strong back-and-forth motion through some pulleys, for moving larger parts, such as windows, drapes or doors. In P.R. CRANE this is the UP / DOWN cable lift motor.

Stepper motor assembly with cogged-belt drive: This is the original Print Head motion assembly. The long belt moves the printhead carriage back and forth along a metal shaft. It originally included a zero-position sensor and a step-motion sensor that might be reused in some applications. It may be coupled to various back and forth mechanisms. It could be removed from its original configuration and the belt drive could be used for other devices. In P.R. CRANE this is the RIGHT / LEFT cab rotation motor.

Control Panel: Easily removed from the case, contains 3 push-button switches that may be connected so the PC can see if they are being pushed. Contains a Power-On LED, a Paper-Out LED, and two more LEDs that could be controlled from the PC if rewired.

Paper-Out Switch: A sensitive mini switch that could be removed and used for other things such as a position or end-of-travel or safety sensor. Can be read from the PC.

Printhead: A marvel of sub miniature engineering. 9 tiny electromagnets drive tiny levers that launch weighted wires at the ribbon and paper to make clear dots. Modular and easily removed from the printhead carriage if not being used.

---

[19]Don’t recognize any of this stuff?? You may want to do steps 1 through 11 of the instructions, and then go through Appendix D on page 16 which introduces some of the way the printer is built.

If you come up with some cool use for these, Email us! Also tell about it on comp.robotics.misc and/or bit.listserv.edtech if you can append to News Groups.

APPENDIX D: Graphics Printer design & construction

The IBM 5152 Graphics Printer is a good example of the way electronic and mechanical devices are designed and built. If you're interested in eventually designing and building your own devices you can learn a lot by looking at the printer in detail (Since you have it all apart anyway!), and figuring out why it is built like it is. We'll give you some observations along the way. You won't understand everything you see in 5 minutes, but if you slow down and look carefully, and read along, in 1 hour you'll be surprised how familiar many parts will be. So, let's start...

Electro-Mechanical Devices

Printers are ***Electro-Mechanical*** devices. This means that they are a combination of electrical devices and mechanical parts that work together to provide functions that are more complex and more interesting than purely electrical or mechanical things.

An example of a purely **electrical** device is a modern clock radio. Almost all the function is in a few silicon chips with no moving parts. (Of course there *are* a few devices that are partly mechanical, such as the switches, and perhaps a tuning knob). But these days you can expect a clock radio that you just talk to, and it puts out sound and has a visual display, and there are no buttons. Well, if you think about it, the speaker is an electro-mechanical device that is electrically driven and moves air to make sound waves. Hmmm. Until the brain-wave GrokRadio I guess we'll still have partly mechanical devices.

An example of a purely **mechanical** device is a hand-driven egg beater. Everything is totally visible and obvious. Of course you can make a mixer with an electric motor, and add an electronic speed control and even a torque control with a microcomputer in it! Most really interesting things are part electrical and part mechanical.

Our printer has some fairly complex combinations of electrical and mechanical devices, such as computer-controlled motors with position sensors. This subject is called *Motion Control*, and is the basis for some of the more complicated modern devices such as robots, aircraft automatic pilots, and remotely controlled spacecraft. This is an exciting area to work in, because the things you work on actually move and respond to your commands. Our printer is a special-purpose robot, with two embedded[20] computers, that can handle materials (paper), position them properly, and do operations on them (make precise marks on them). When we modify the printer using the instructions in this manual, we will take over control of the motors in our own software, and we can experiment with how they work, and decide to give them new and different functions.

Construction techniques and materials in the Graphics Printer

NOTE: You should actually do steps 1 to 8 of the step-by-step instructions at this point, and then pick up here, looking at the real printer!

[20]Embedded microcomputers are internal parts embedded (stuck down inside) in some system like a car, a microwave, a Furby, a Virtual Pet, or a Video Game.

Find the different subassemblies that make up the printer:

Control Panel: Unplug the Panel from its cable, and hold it so the switches and green LED's are on top, and the label "MPEL" is on the lower right, and the lettering is right side up. If you unstuck the plastic label legend from the cover, get it too. What's here?? Basically a flat plastic panel with parts mounted on it. What parts??

- **Switches:** Three square push-button switches are used for Line Feed, Form Feed and Online functions. Look for the *component identifications* printed just above them (SW1 , SW2 and SW3). Temporarily put the plastic legend over the switches so you can see how this looked in the original printer. These are *momentary* switches (they are only ON when you hold the button down). Now, what holds them on the panel? Turn the panel over and see that there are two small silver-colored blobs where each switch is located. There are holes drilled through the panel and small wires from the switches come down through the panel to the bottom, where they are *soldered* (lead-tin metal is melted onto them and then cools off and becomes solid). Soldering is like Hot Glue with melted metal instead of melted plastic.
- **Printed Circuit Board:** Now that we notice that the Control Panel is really some switches and other parts put on a panel or board, let's find out about it. The **Printed Circuit Board** has two functions:
  - **Printed Circuit:** Look at the back side of the board, where we saw the switch connections were soldered. There is a pattern made up of lines that run around on this side of the board. The board is mostly painted with a green transparent coating to protect the pattern, which is made up of copper metal. Take a bit of sandpaper or a dull knife and scrape off the paint on a little part of the pattern. See? It's bright copper, and functions as **wire** that connects things on the board. Someone took the *circuit* that connected the correct switches and LED's and other parts on the board, and figured out the *pattern* to make to connect them properly. This can be a challenging job: because *the lines can not cross each other*! They are on one *plane*. This job is called "Printed Circuit Board Layout". There's more about this in the Glossary. The pattern was *printed* on the board, much like a photograph.
  - **Board**: The other function of a circuit board is to physically mount the parts that are being used, and hold them in place. It becomes the chassis or frame that the other parts are mounted on. The push-button switches are mounted on the board by fitting through holes drilled in the board and being soldered in place. The board itself is usually made of glass-epoxy which is a fiberglass fabric that has liquid epoxy plastic resin soaked into it, which is then hardened. This is the same material that most motorboats and sailboats are made out of these days. Notice that the board has printing on it that identifies the parts, it's own unit number, and the manufacturer (Epson in this case).

- **LEDs (Light Emitting Diodes)**: Are marked LED1 through LED4. Look at the plastic legend to see what they were used for. OK, LED1 is labeled <u>Power</u>, LED2 is labeled <u>Ready</u>, and so on. You must have seen little lights like these on many types of electronics equipment. LEDs are usually Red, Yellow or Green, although recently there have been some made that are Blue or White which are more expensive. LEDs are cheap (10 cents for a Red one), don't wear or burn out, and take only a small amount of current (.01 amp) to light up.
- **Resistors:** Are marked R1 through R4 . What are they *for?* Let's see what they're hooked up to, first. Hold the control panel so that the LEDs are on the right, and LED1 is on the top.

Now, turn it over while watching LED1 so you can find it's two connections on the bottom. OK? Now, look at those two connections, one on top and one on the bottom. Notice that the bottom connection has one of the circuit traces (wires) coming from it. Follow that circuit trace down the left side of the board until it ends at another connection. Slowly turn the board back over while watching the connection. You'll see it goes to one end of R3. (This is called *circuit tracing*, and if you have the patience and good eyes or a good magnifying glass, you can *trace* a whole circuit and write it down.) Now, we know: LED1 is connected to R3. So why? Well, the current going through LED1 has to be *limited* or it will burn out. Current is usually limited by using intentional *resistance*. Where do we get intentional resistance? With a *resistor*, of course! Look closely at R3. It's a little cylinder of brown plastic about 1/2" long and 1/8" in diameter. Wires come out each end so it can be connected easily. The wires on R3 go down through holes drilled in the circuit board, and are soldered in place just like LED1 and the switches are. Look more closely at R3, and notice it has 4 colored bands running around it. At one end they are close to the end, so start there. The colors are:

GRAY RED BROWN SILVER and the *colors* [21] each mean a *number*, like this:
8 2 1 5

The first two colors are the first two numbers of the value, and the third color is the "number of zeros to add after the first two numbers". Like this:

8, 2, 1 zero (so the value is 820)

The last color is "how accurate is this resistor". SILVER is 10% and GOLD is 5%

So, after all that, we can tell that R3 is one of those mysterious parts we see on some electronics parts list when it says:
R3 820 Ohm 5% Resistor

You *CAN* figure all this stuff out, with some patience, and a little knowledge of how it is done! Now, what parts are left?

- **Buzzer:** This part is labeled "**BUZZ**" and is next to LED1. It is the buzzer that is used to tell the user that the printer is out of paper. It changes electrical power to sound waves.
- **Connector:** labeled "**CN1**" is where the cable from the rest of the printer plugs in. Notice it has metal pins that "go down through holes in the circuit board and are soldered in place". (Heard that before? That's how most electronics parts are put in place.)
- **Capacitor:** Labeled "**C1**" and hiding just above SW3. It's another type of electronics component. This one is connected between power and ground to help smooth out the electrical power on the control panel.
- That's about it for the control panel. Oh, there *is* one more thing ... It's a round metal cylinder in the upper left corner next to BUZZ. What does it do?? It doesn't touch anything, including the printer cover. I've never been able to figure out what it's for! Maybe it's an Uncle Burt thing.[22] If you figure it out, *please* let me know![23]

---

[21] Look at *RESISTOR* in the glossary for the rest of the *Color Code*
[22] On the Farm, I asked my Uncle Burt 10,000 times "What's *that* for?" One of his stock answers

APPENDIX E: Troubleshooting

Troubleshooting is more like an attitude than it is like a job.

These are the things that must be right for P.R.CRANE to work right:
1. The software must be talking to the right printer port.
2. You must have a normal printer cable connected from the port to P.R.CRANE
3. The printer used must be basically working: Test it *before* you modify it to be sure.
4. P.R.CRANE must have the right 8 jumper wires installed inside, and they must be making an OK connection.
5. P.R.CRANE must be plugged in!

was 'To make little boys ask questions!' Then he'd explain. I learned a *lot* on the Farm.
[23]Email: tking@together.net

APPENDIX F: P.R.CRANE Software

P.R.CRANE software comes from our website at http://homepages.together.net/~tking

You will download a file called PRCRANE.ZIP

A "ZIP" file is a *package* that is easy to ship around the Web, and contains several objects that you will need. But first, you will need a program called PKUNZIP.EXE to open up the ZIP package and recreate its contents. If you're not sure you have this program, go to a DOS prompt on your computer and type PKUNZIP. If you get a message 'BAD COMMAND OR FILE NAME' then you *Don't* have it! If you have a Windows system, look for WINZIP.

You can get PKUNZIP for any machine, DOS or WINDOWs etc, on the Web at:
http://www.pkware.com/shareware

After you have PKUNZIP, decide WHERE on your machine you want to put P.R.CRANE software. You may want to make a subdirectory on your C: or D: drive like this:
MD C:\PRCRANE
and then change to that subdirectory like this:
CD\PRCRANE
Then, copy the PRCRANE.ZIP file to this location.
THEN, run PKUNZIP like this:
PKUNZIP PRCRANE.ZIP

NOW, if you look at the files in your subdirectory, you should see several, like this:

```
FILENAME          SIZE        DATE/TIME       WHAT IT IS
------------     ---------  ---------------  ---------------------------------
PRCRANE  EXE        25,680  03-29-99  1:06a  The main program to run P.R.CRANE
PRCRTEST EXE        11,792  02-25-99  1:33a  Test program for first tryout
CRANEOFF EXE         3,872  02-20-99  1:48p  Safely turns off P.R.CRANE Motors
SEEBITS  EXE        14,448  10-19-97  5:29a  General Purpose 'Parallel Port' Pgm
READMECR TXT           388  02-14-99 11:51p  Read Me about P.R.CRANE
SPEEDTST CRL           442  03-29-99  9:38a  Sample P.R.CRANE program: tests
TRYLEARN CRL           186  03-28-99  9:56p  Sample program created by LearnMode
TRYLOOP  CRL           145  03-26-99  7:32p  Sample Program that loops (repeats)
PRCRANE  PAS        55,219  03-29-99  1:05a  ** SOURCE CODE and UNITS for above
PRCRTEST PAS        13,585  02-25-99  1:33a  ** Programs, for those interested
CRANEOFF PAS         1,599  02-20-99  1:47p  ** in understanding or modifying
CTRLBRK  TPU         1,120  10-19-98  7:26p  ** the internals of the programs.
PARPORT  TPU         6,368  12-08-97 10:32p  **
HEXUTIL  TPU         9,504  06-10-97  6:40p  **
KBDINPUT TPU         4,048  10-16-97 10:30a  **
```

All you need to start is to read the READMECR.TXT file, and then use PRCRTEST for your first tests, after you do the previous Step-By-Step instructions on how to add the wires for a P.R.CRANE. If that works OK, run PRCRANE.EXE and you're off and lifting...