

Ed Bertschy's Paper Steam Engine



Note: This document and all artwork is yours to use as you see fit. The author has placed it in the public domain and encourages others to use, distribute, modify, add to and otherwise share it. Enjoy.

This is Version 2.0, with thanks to Tim Kirby, Kerry Hotker and Giuseppe (PINO) Civitarese for their excellent feedback.

Changes in this version: The governor base has been replaced with one that works. Special character fractions have been eliminated in the text All files are now .pdfs including instructions.. Page number 8 of card stock pages has been correctly numbered. A small change was made to the drawing on Page 2 of the Instructions.

Outline of Pages:

Before you begin.

Introduction.

Tools you will need to complete this model.

Building rules of thumb.

Printing and Paper.

Two theories on construction.

Nomenclature

Instructions

Section 1

Base and A Frame, assemble.

Section 2

Flywheel, crankshaft, crankshaft stool, cranks, piston rod connector end, assemble.

Section 3

Cylinder, piston, piston rod, slide valve, valve chest, crosshead, crosshead slippers, assemble.

Section 4.

Eccentric and strap, governor pulley, crankshaft, crankshaft stool, assemble.

Section 5

Slide-valve connecting rod, assemble

Section 6

Boiler feed pump and link, assemble

Section 7

Governor

5 pages of building and assembling tiny annoying parts to build a really trick Watt type governor.

Section 8

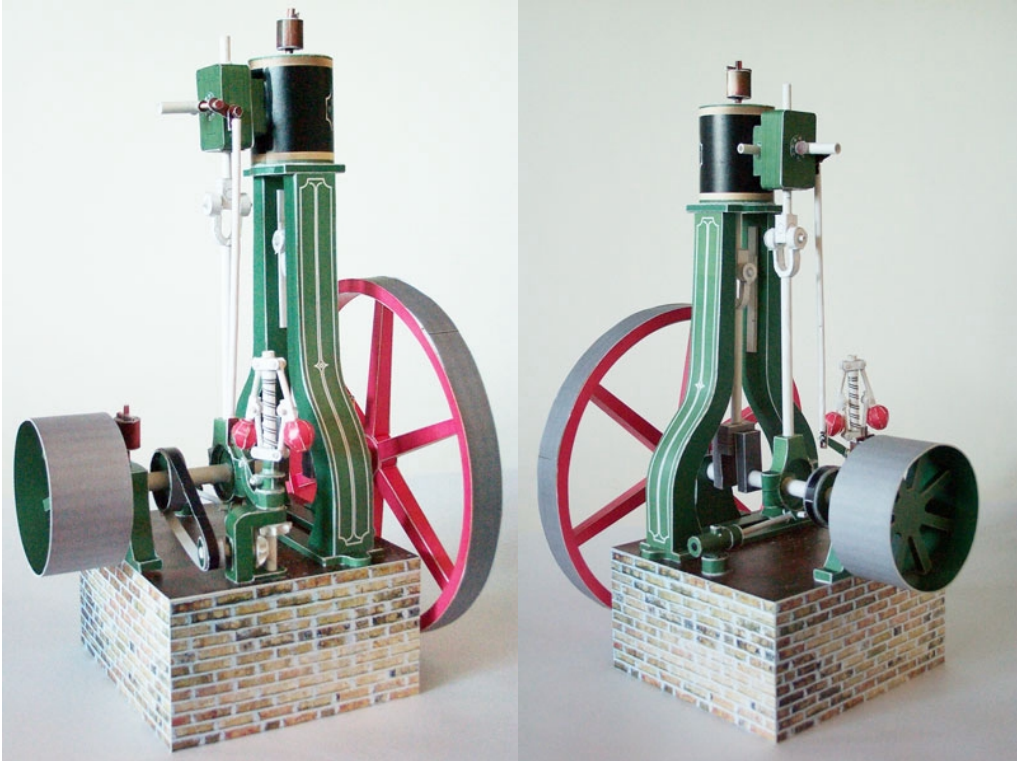
Governor butterfly linkage and oil cups

Section 9

Power wheel

That about covers it.

Ed Bertschy's Steam Engine



Introduction

This model steam engine would never have been made if not for the hard work and generous nature of Richard Adamek. He has created a website which provides volumes of technical information about stationary steam engines, and more importantly, a Cad drawing showing all of the parts of a steam engine he rescued and restored from a scrap pile. He has a small museum known as the Old Engine House (<http://oldenginehouse.users.btopenworld.com>) where he displays the results of his hard work.

This paper steam engine is based on his cad drawing of a Riches and Watts nominal 2 1/2 horsepower vertical A-frame double acting simple slide-valve steam engine circa 1870-75. The original engine was used to drive a water pump to irrigate the fields of Norfolk. If this model had a scale, it would be roughly 1:19. I had to double the size of the eccentric and strap in order to make it buildable. Everything else is close to scale, but changed in design and appearance because, well, paper isn't iron.

While this looks like a really complex model, when broken down into its various sub assemblies it is more of a collection of small boxes and tubes that fit together in a pretty straightforward manner. There is nothing too complex, even for relative novices to tackle. When finished, it is designed to run by turning the flywheel. If you are so inclined, it would be a good candidate for motorizing, and if you are one of those rare brilliant people who love a challenge, it can be made to run under compressed air, like a steam engine.

This set of notes is meant to accompany a series of drawings illustrating the building of sub-assemblies, and another series of drawings illustrating final assembly. It is a good

idea to print out the instructions and the drawings so you can refer back and forth between them.

I hope you enjoy this model. I am providing the files free because I hope you will have as much fun building and showing it off as I did designing it.

Ed Bertschy, 2002

Tools you will need to complete this model.

You are going to need white glue (Elmer's is still the best after all these years.)

A sharp hobby knife with a pile of pointed blades. (Or, whatever you have for precision paper cutting).

Some way to drill holes in paper. I use an X-acto® knife to drill a small hole, then expand it with a round needle file. A 1/16th paper punch comes in real handy when building the governor.

You will need a way to make a fine score, or dent in paper. I use a dull compass type divider.

A metal straightedge.

A set of four rods of different diameter for rolling paper around. 1/16th inch diameter, 1/8th inch diameter, 3/16th inch diameter, and 1/4 inch diameter: I use a straightened out paper clip, a coat hanger, a brass tube I got in a hobby shop and a piece of basswood dowel.

Note: purists (like me) will want to make all of the crank shafts, pins and connecting rods out of paper, and this model includes them. Others can use balsa dowels, bamboo BBQ skewers, Q-tips or what have you. I've noticed that some people just hate making tubes, rods and pins out of paper.

Other nice things to have: An 8" diameter cookie tin makes a good jig for building a spot-on perfectly circular flywheel. (Another excuse to buy cookies.) A little sandpaper or an emery board. Scissors, a shoebox, patience, a sense of humor, and a ponytail all come in handy too. (In joke)

Building Rules of thumb and how to read the instructions.

On each page you will see a bewildering cloud of tiny arrows. A red arrow means cut here, the blue arrows mean score. As a general rule, score everything in the part before cutting anything out. Scoring after cutting can be real tricky and can mess up the part. Scoring curves, and there are very few of them, has to be done with a steady hand, or using a jig of some kind, like a spool or a french curve.

Most pieces have some kind of hole in it to be cut out. Do not cut these out before you build the part. Almost all of them will need to be closely fitted onto a hand made paper rod, shaft or pin. Hand made paper rods, pins and shafts can be just about any diameter when done. So build first, drill later. There is a large amount of hand fitting and adjusting in this model. Rod lengths are frequently not given for this reason. Make the longest rods and pins you can, and cut them to length when you need them. You will know how long to make them by fitting them in place.

Printing and paper.

I designed this model using two papers:

Hammermill premium laser paper for color laser printers, and Classic Crest Cover Solar White Super Smooth cover stock. Sub 80/216g/m². Both stocks are 8 ½ x 11. I printed the pages on an Aficio 6010 color laser copier like you find in Alphagraphics and Kinko's. These files are in .pdf format and should print fine on your ink jet. Be sure to turn off any "fit to page" setting when printing the parts. If you can take the files to a printer and have them printed using a color laser copier on cover stock and premium laser paper, you will be much happier with the result. You can also print the pages entirely on an ink jet and glue the card pages to cardstock. It works just fine. Heck, print them in greyscale and paint it if you want.

There are four files: Assembly Instructions, Assembly Illustrations, Parts for Card Stock and Parts for Paper Stock

Assembly Instructions: 13 pages. Assembly Illustrations: 29 pages. Parts for Card Stock: 10 pages. Parts for Paper Stock: 4 pages.

You need only take the parts pages to a printer. The rest are instructions for information only. All told, there are 248 parts to cut out on 14 pages of model parts, with 29 pages of illustrations and these instruction notes and we're already on page 6. In a perfect world, these pages will have no omissions or errors, but that is not the way to bet. Hopefully, you will be able to puzzle out how to make this from all the drawings and notes. If not, I recommend joining the papermodels newsgroup at (<http://www.smartgroups.com>) I guarantee someone there has heard of this model and can help, or at least sympathize. You might even find me there to yell at or complain to.

Two theories of construction.

Do you cut all of the pieces out first, or build as you go?

For this model, I found it easiest to cut out all of the pieces, then build the sub assemblies, then assemble the final model. Of course, I didn't find it easy to do that until I had built about 10 of them, and knew every scrap of paper by heart.

So, with the help of the good folks at papermodels at smartgroups.com, I was able to come to my senses and fashion a plan of attack. The final assembly is divided into nine different sections, each section ending with the assembly of the pieces added to the final model.

These written instructions are meant to augment the illustrations. Once the pieces are cut out and built, you then assemble them as per the final assembly page of section one. Then, go on to section two, where you will repeat the process: find the parts, assemble the sub assemblies, then final assembly of section two. Continue until done.

I have tried to keep the subassembly pieces together on the same page. There are some exceptions, and it can be a bit of a treasure hunt to find some parts. I will try to list page and part number together when I mention a piece. The format will be (Page #, Part#) and look like this: (3,25) They can also look like this: 3, 134 - 135 when multiple identical pieces are specified.

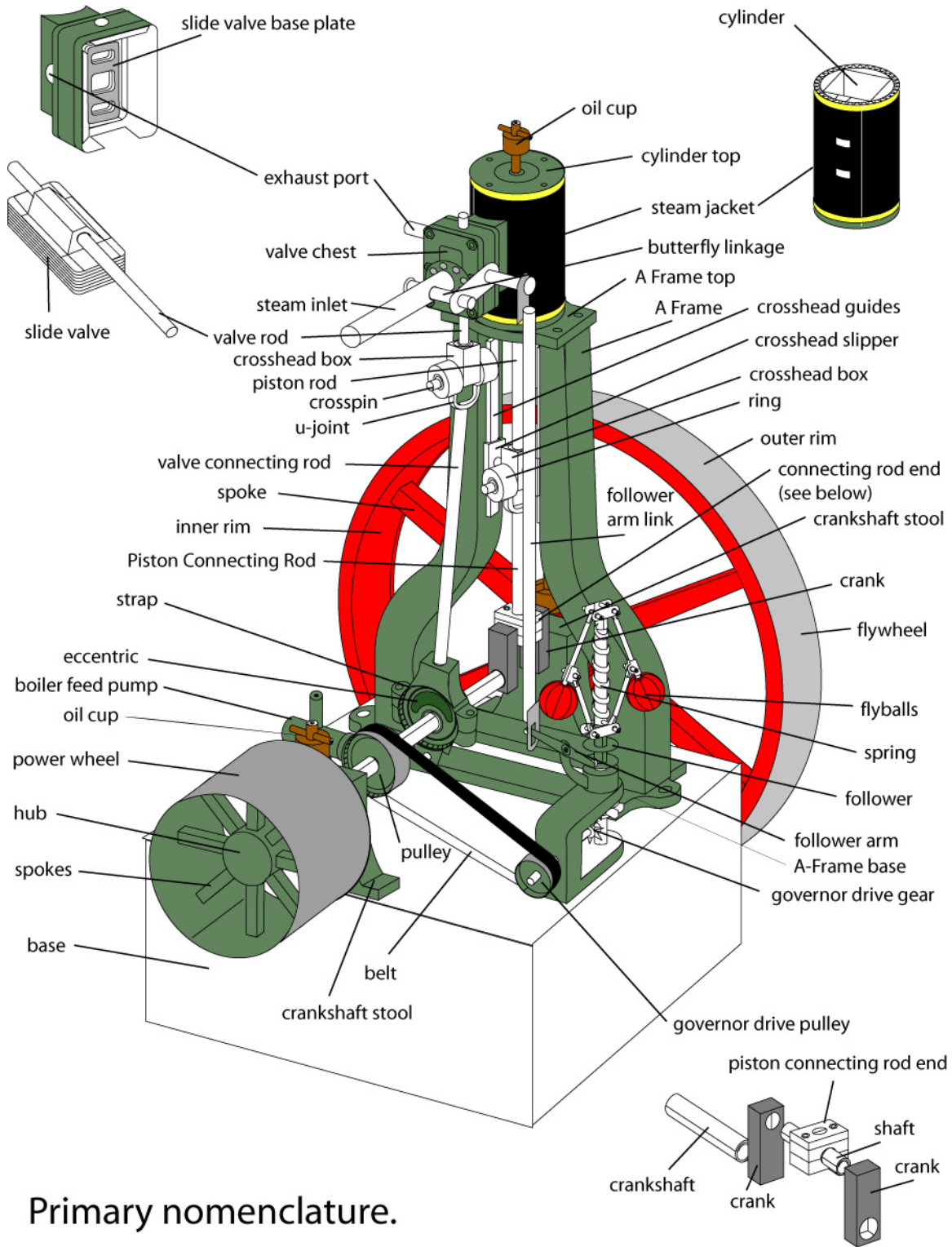
When I was cutting and gluing, it took three evenings to cut out all the parts and three evenings to build. A three day weekend should be sufficient to build this model if you don't mind being yelled at for not getting anything else done.

The flyball governor is a special case. It takes at least two days to build because the flyballs need to dry overnight. It is also a right complicated little beast, that is fully functioning, and you need to exercise care in its construction because it is also small. It has four pages of subassembly instructions of its own. This would make a good kit all on

its own if it were blown up about 300 percent. Anyway, you build it in section seven. This model can be built without a governor and still impress a lot of people. In fact, by the time you get to section 7, you will be showing it off already, I am sure.

I want to encourage anyone to modify, correct, change and improve this model, then share your fixes/mods/corrections with others. You can even replace the Bertschy manufacturers plate with your own design. By the time you are finished, you will have earned it.

Well, that's enough jabbering. Let's build a steam engine.



Primary nomenclature.

Section One: The Base and A Frame

Pretty straight forward. Follow the illustration. Page 5 is printed twice, so there is an extra long support that is not used.

The A Frame

You will see on parts page 3 that the areas to cut out in the frame top and base are colored blue. This is because the white areas are for gluing the frame to the base and top. The paper glues better with no toner, and this frame needs to be strong.

The white rectangles inside the A frame are the crosshead guides. They don't need to be closed on the ends.

Those A frame sides are a bit tricky. When done, they need to be able to lay flat, and stand straight. You can fudge a little because the top and base matches the ends up and forces them to be parallel. The best way to make them is to start with 20, add 16, then 18, and finally 21

Final assembly is a no brainer.

Section 2: Flywheel, Crankshaft, Crankshaft Stool, Cranks, Piston Connecting Rod End

The flywheel is pretty straight forward. When cutting out parts 26, 27, and 28, the dotted lines are cut. They stop short of going into the red, or going through the white strip.

When formed into a rectangular tube, they are very flexible. The best way to assemble a solid perfectly round flywheel, is to use a cookie tin as a jig. The flywheel rim needs to fit snug, but not too tight around the cookie tin. The gray outside rim is too long on purpose. You will need to cut it down to fit when you wrap it around the outside of the wheel.

Glue the white sides of the spokes to the white side of the outer face, and flush with the ends. Put in the hub in next, then the inner face of the wheel. Do not cut out the hole for the crankshaft yet.

The spoke ends cover the white squares on the inside of the rim.

Crankshaft, Cranks, Piston Rod End and shaft.

All of this stuff will be clearer if you look at the Section 2 final assembly page as you read this.

The crankshaft is made from rolling a sheet of paper (page 10) around a 1/4" dowel, and gluing the outside edge, then removing the dowel. You will only need about 2 inches for this assembly. When dry, cut a 2 inch long piece from the end.

The shaft that goes through the piston rod end is smaller in diameter than the crankshaft, but is made the same way. It is cut from the end of the Piston Connecting Rod on page 11. Cut 1" from the end of the completed rod, and save the rest for later. The Piston Connecting Rod End is a box (3,47) with a shelf (3,48) in it. The shelf lines up with the upper line on the outside of the box.

Do not cut the holes out for the cranks. First glue them together and let them dry. Then carefully cut out the two outside (larger holes) to allow a press fit for the 2" crankshaft piece. Then carefully cut out the two inside holes for the 1" shaft, and the hole in the middle of the piston rod end to allow a press fit for the shaft to start inside one crank (545), go through the piston rod end (3,47), and into the other crank (5, 46). Glue the crank, the small shaft, the piston rod end, and the other crank together. Make sure the piston rod end (3,47) turns freely around the shaft, and is as perpendicular to the shaft as possible.

Carefully cut the crankshaft stool holes to allow the crankshaft to tightly fit through as straight as possible. Then glue the stool in place for test fitting the cranks. Glue the crankshaft into the hole on one of the cranks. The spacers on page 5 are used to adjust the placement of the crank and piston rod end directly under the hole in the top of the A

Frame. Place the small spacer on the shaft, and slide the shaft through the stool with the cranks inside the A Frame. Place the larger spacer on the crank, and fit the flywheel onto the end of the crank. Carefully cut the hole in the inner face of the flywheel to allow a press fit of the crankshaft. No matter how hard you try, there is going to be a little wobble in your flywheel, especially when you have only 2" of the crankshaft in place. The spacer is to keep the flywheel from rubbing against the side of the base. If the flywheel clears the side of the base, and there is no side to side slop on the crankshaft, then glue the crankshaft into the Flywheel. Otherwise, make the crankshaft shorter or longer as needed. When done, the flywheel should turn the crank assembly freely, with little wobble and no side to side motion of the cranks. The cranks should be centered under the hole in the top of the A frame.

Section 3: Cylinder, Slide Valve, Valve chest and Piston Connecting Rod.

This section is actually a lot easier than it looks. Remember, this model can be built to run on compressed air, so all of the internal parts are there to do that. If you intend to run it on air, you will be advised to build one first, so you can see where it needs to be sealed, and how the air flows through the model. These instructions show how to build it, but not how to build it so it will run on compressed air. That requires precise fitting, lubrication, and sealing of parts. These instructions build a model you can motorize or run by turning with your finger.

The cylinder. Part 8,49 forms a square tube. This is our cylinder. It is square because after building a dozen of these with circular cylinders, I found it is almost impossible to make one come out round. Square works much better and runs more smoothly with half the work.

OK, cut out the square holes in the side of 8,49. This is where the steam enters the cylinder. Note the two steam ports 8,51 and 8,52. The holes on the sides will match up with the holes in the cylinder (8,50) and the steam jacket (8,53).

After you have built cylinder, steam jacket, the piston and rod, start a small hole in the bottom of the cylinder. Widen it just enough for a tight fit of the piston rod. Run the piston up and down inside the cylinder. The rod should stay straight the whole length of the cylinder. If it does not, then widen the hole until it does. If this leaves a wide hole in the bottom, cut a small piece of green paper with a hole just big enough for the piston rod, and glue it to the bottom of the cylinder, making sure the rod is positioned to go straight up and down.

See how "hand made" these engines are? Every one is different.

Once you have the piston going straight up and down, pull the piston down until it is just above the bottom hole, then mark the shaft with a pencil where it comes out of the bottom of the cylinder. Then push the piston up until it is just below the upper hole, and mark the shaft again. These marks will tell you where top dead center and bottom dead center are.

Glue the top on the cylinder.

The valve chest.

The illustration is pretty straightforward. On section 3 page 2, the valve chest cover is put on like a door, and tucked under the opposite side flap. You should leave it this way,

perhaps permanently. Unless you are sealing it to run it on air, this door will let you see the timing of the valve, and show off your hard work.

Make sure the slide valve and rod are pressed against the valve chest base (8,60-65). The two gray faces, one on the valve chest and one on the slide valve itself, should face each other. The slide valve should move smoothly over the face of the valve chest and be pressed against it. It should also move in a straight line.

Glue the valve chest and slide valve assembly onto the side of the piston cylinder so that the piston rod and the valve rod are parallel. The valve port box (8,57) should just cover the two holes in the side of the steam jacket.

The crosshead and connecting rod.

Study the photos and drawings thoroughly. You want to look at how the piston rod is connected to the crankshaft.

The rod which comes out of the cylinder is the piston rod. The rod which connects the u-joint to the crankshaft is the connecting rod.

The flaps at the ends of the U joint fold outward to make a little shelf for the rings to rest on. Cut a hole in the bottom of the U to glue the piston connecting rod into. Remember, you made this rod and used a 1" piece for the crank. The cross pins should fit as tightly as possible through the rings, so cut the holes last. The diagram on Section 3 Page 4 shows how the piston rod rests on the cross pin, and the two crosshead slipper rods (12, 122 & 123) rest up against the piston rod. Build the u-joint and glue the connecting rod to it. Build the crosshead slipper, but do not glue it to the piston rod. All of the holes should be cut at this time. Fit the crosshead box to the bottom of the piston rod, the lower holes to the cross pin, and the middle holes to the slipper rods. Test fit the slippers and make sure they fit between the uprights of the A-Frame (see illustration and photos). Adjust the length of the slipper rods until they fit and the slippers slide easily up and down the crosshead guides on the inside of the A-Frame.

Glue the Piston cylinder and valve assembly to the top of the A-Frame as shown. Turn the flywheel until the crank is all the way down. Pull the piston rod down until the top mark on the rod shows. Cut the piston rod off at $\frac{3}{4}$ " above the bottom end of the crosshead guides. The exact position is not critical. Just make sure it is straight. Next, push the piston rod up until it hits the lower mark. Now fit the slipper onto the guides, and slide it up until it comes to the bottom of the piston rod. Put glue on the end of the piston rod, and glue the crosshead slipper assembly onto the bottom of the piston rod. Let dry.

Pull the piston rod down until the upper mark shows. Turn the flywheel until the crank is straight down. Measure the distance from the center of the crosspin hole, to the upper line on the side of the piston connecting rod end in the center of the crank. Make sure the hole in the top of the connecting rod end in the crank is pointing up. Measure the same distance from the center of the U Joint rings, to the bottom of the connecting rod, and cut the connecting rod off. Set the connecting rod in the hole in the top of the connecting rod end in the crank, and mode the crosshead slipper so that the bottom holes line up with the u-joint rings. Push the crosspin through the u-joint rings and the bottom of the crosshead slipper assembly. Don't glue anything yet. Carefully turn the flywheel until it is all the way up. It should push the piston uop to somewhere near the

lower mark. Turn the flywheel and move everything to bottom dead center. Test to make sure the piston is not hitting the bottom or top of the cylinder. If it looks like everything will work, and clear, then remove the cross pin, pull out the connecting rod and U-joint, put some glue in the hole in the top of the connecting rod end in the crank, (not too much, there is a shelf inside, but you want to keep the glue off of the crank shaft that goes through it). Replace the connecting rod, reconnecting the u-joint to the piston rod and let dry.

When dry, try turning the flywheel by hand to get a feel for how the parts move. You don't want it to catch anywhere or rub where it shouldn't. Everything should be perpendicular to each other.

Section 4:The eccentric and strap.

The eccentric and strap is essentially a wheel within a wheel. The middle part will turn inside the outer part. The outer part connects to the valve rod in exactly the same way as the piston rod connects to the crank, but without any crosshead slippers.

The two pieces (4,90 & 91) face outwards, and the middle pieces make it a single disc. Do not cut out the hole in the middle disc (4, 90-95) until ready to mount.

Do cut the hole out of the middle of 4,89 and 4,96. When 4,89 is placed inside the rim, it makes a ledge for the middle disc to rest on. It must be flush with one edge of the rim. It must also be dry when the middle disc is placed on it. Once the middle disc is placed inside the rim, carefully put a little glue around the inside of the rim, careful not to get any on the middle disc. Then push piece 4,96 into place over the middle disc. Make sure the middle disc can turn freely inside the outer rim.

Add the outer pieces to the rim.

Next, get the crankshaft and carefully bore a hole through the middle disc, just large enough for a tight press fit of the crankshaft through the eccentric. Notice the hole is off center, This is what makes it work. You should be able to turn the crank, and the eccentric should turn without gluing the eccentric to the shaft.

Once this is done, complete the assembly as shown in section 4 final assembly.

Do not glue either the pulley or the eccentric to the crankshaft. Glue the crankshaft to the crank only.

Section 5: Hooking up the valve.

This is just the same as the piston, but no crosshead slippers. First off, set the crank to the 9 o'clock position. Then, grip the center of the eccentric and turn it until it is at it's high point, the "half moon" pointing up. Open the front door of the valve chest, and push the slide valve rod up until the slide valve is just short of the top of the valve chest. Cut the valve rod (not the connecting rod) off at one inch below the bottom of the valve chest. Put a crosspin in the connecting box, and glue the box to the bottom of the valve rod. Let dry. Remove the crosspin.

Now, build the connecting rod and U-joint just the same as you did for the piston connecting rod. With the eccentric in top position, and the slide valve just below the top of the valve chest, fit the connecting rod so that the rings meet the center of the valve rod end, and the connecting rod end goes through the hole in the top of the eccentric strap, and rests on the rim itself (inside the cone shaped box on the top of the eccentric strap). The pictures and drawings show it pretty clear. Make sure the eccentric is directly under the valve rod and is 90° advanced to the crankshaft. If all is cool, try turning the flywheel and checking that the slide valve clears both ends of the valve chest when the

eccentric is all the way up, and all the way down. Make sure everything is lined up straight, and remove the valve connecting rod, put glue in the hole in the top of the eccentric, and replace the connecting rod.

Now, if everything is still lined up, and 90° out of phase, put a drop of glue where the crankshaft passes through the eccentric. Turning the flywheel at this point will make the valve slide up and down, as well as the piston. It is cool.

Section 6: Boiler feed pump and connecting rod.

The boiler feed pump, and connecting rod are easy. Just remember, when placing the boiler pump, it has to be close enough to the eccentric that the connecting rod won't pull out, or collide with the vertical shaft inside the pump.

Section 7: The Watt Type Governor.

To form the flyballs, use the rounded end of a fat pen to form the dome. You can even glue them down to the pen, and then release the pen when the glue dries.

The "spring" is only glued at the ends, so that it compresses and stretches out when the follower slides up and down the central shaft.

All parts of the governor need to slide, rotate or move easily with no binding. Loose is better than tight. Too loose is too loose.

Section seven page four is important. There are two types of gears. One is built with all parts glued to the shaft, and the other is built on a shaft, but made to be slipped off when done. You make both gears with rectangular teeth. Then, fill the space between the gears near the center with glue. This makes them very robust.

The box at the bottom of the page is reference for getting the gears to mesh smoothly AFTER you have fully assembled the governor. I have found through trial and error, that if you trim the gears in the manner shown, after assembly, the governor will work much more smoothly.

The pin at the bottom of the governor central shaft is made by tightly rolling some scrap paper.

The crankshaft pulley should be set far enough away from the A-Frame so that when the governor is placed, it will not strike the A Frame when the flyballs are fully extended and spinning around.

The belt. Here it becomes your choice what to do. I have used rubber bands, and even used a sprocket and slotted belt arrangement to make the governor turn when the flywheel is turned. If made properly, a paper belt will do the trick. If you find that it does not, then try a rubber band, or even better, make a sprocket to put on the end of the governor drive pulley and use a slotted paper belt. But try the paper belt first. You fit it with an overlap, and glue it as tight as the paper will allow without distorting the governor.

Section 8: The governor linkage and oil cups.

The governor linkage should also be easy to move. Part 12, 207 is a teeny tiny pin, and should probably be made from a tiny scrap of paper. The tips of this pin can be glued to

the back of the gray piece connecting the rod to the follower arm. Be sure the follower arm is not glued to the link.

Though it is a little hard to see in the drawing, the exhaust port fits on the exhaust hole the same way the steam inlet fits on the valve chest.

Be careful when placing the oil cups. If they are set too deep into the stools or cylinder top, they could interfere with the running of the engine.

Section 9: The power wheel needs no explanation.

Well, that should about cover all of the stuff not obvious in the drawings.

The best advice I can give you at this point is take your time.

Ed Bertschy eellbee@earthlink.net