Plumbing Part III - Lubricator

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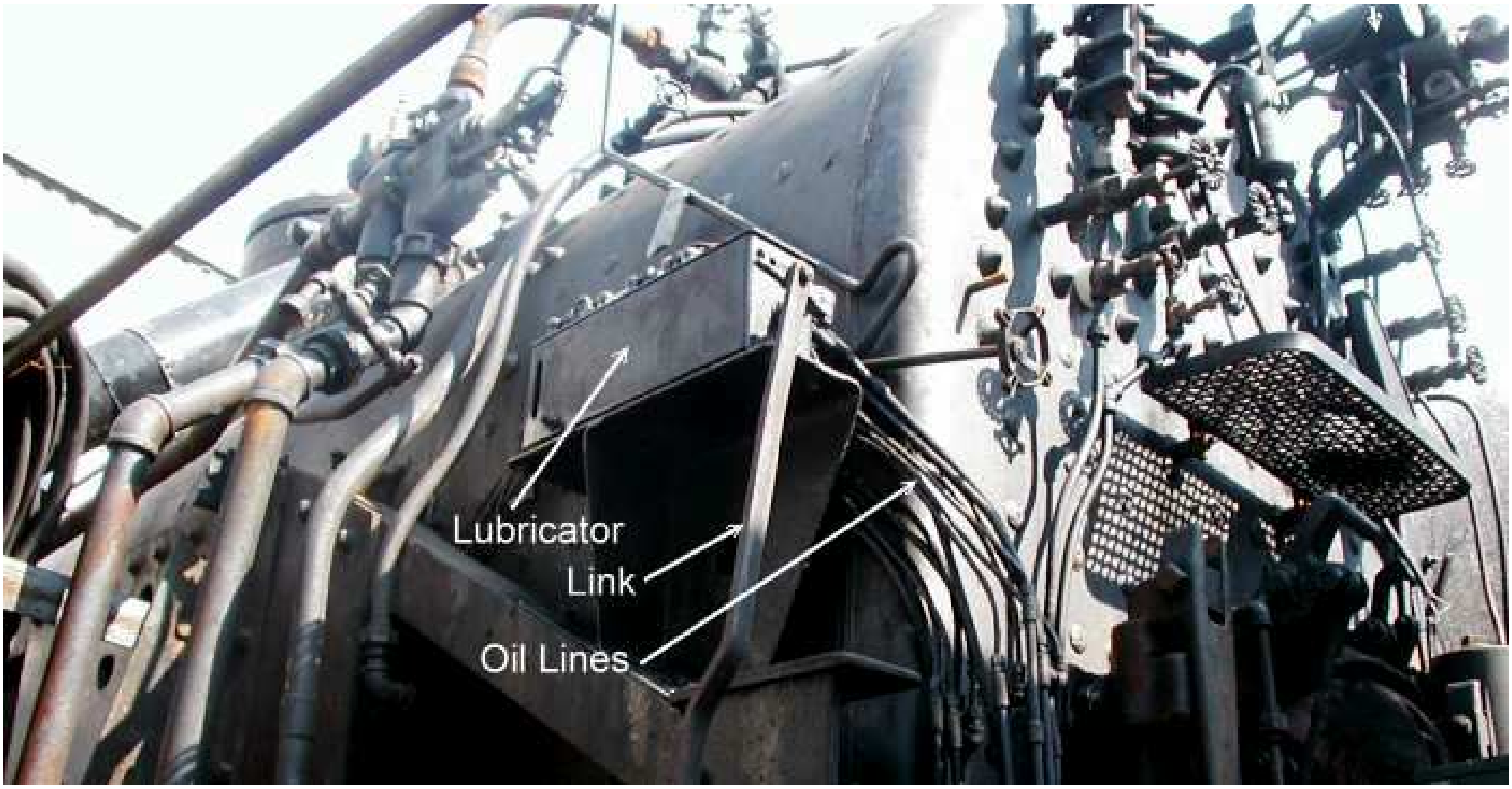
The Lubricator injects oil into the engine intake header to lubricate the sliding valves, piston rings and cylinder walls. A very small amount of oil is required but the pressure must be sufficient to overcome the steam pressure. Two types of lubricators are commonly used on live steam locomotives, the displacement lubricator and the mechanical (pump) lubricator.   The displacement lubricator is a fairly simple device with no moving parts but is not typically used for the locomotive engine -- not sure why. The mechanical lubricator is a simple small pump.

I had just prepared an order for all the pluming parts (valves, unions, taps & dies, elbows, etc.) and was suffering sticker shock. This project was beginning to become a money pit. But when compared to the real money pit (a woman) it's a bargain at twice the price.   However, thought I should maybe economize and build my lubricator since they seem to be selling for about $150. Also, I wanted to be make the tank so it would match the locomotive aesthetics.

I haven't noticed a mechanical lubricator on any of the shays I've seen. Next time to Cass I'll have to look more closely.

However, did snap the following photo of the lubricator on the big Heisler at Cass.



That' a new boiler they're installing. The link connects indirectly to one of the valve eccentrics. As you can see, there are many oil lines. I assume there are many little pumps in the lubricator tank. Next time will have to look more closely.

Live steam mechanical lubricators are driven by a eccentric on an axel or by the engine valve mechanism. In most cases the pump rate is much less than the rate of the driving mechanism. This speed reduction is typically achieved using a ratchet wheel where each input stroke advances the ratchet wheel one tooth and the pump is driven one stroke per ratchet wheel rotation.

The Design: I next looked up the lubricator in Kozo Hiraoka's Building the Heisler. (I prefer to use the Heisler text since the dimensions are in inches; his Shay and Climax texts are in metric. I can make the conversions, but why bother if I don't have to.) For his 3/4" scale Heisler Hiraoka uses a 40 tooth ratchet wheel, a 3/32" pump piston and a 1/4" stroke.

The 1.5" Shay will need more oil. The cylinder surface at 1.5" scale is 4 times the area of the 3/4" scale assuming identical cylinders. The Shay has three cylinders vs. the two Heisler cylinders so should have 50% more for a total of 6 times the oil as Hiraoka's Heisler.

Hiraoka fabricates his ratchet wheel from tool steel that he then hardens. That looked like a lot of work. Then I noticed that Coles lists a lubricator ratchet wheel --- 35 teeth - 7/16" diameter. Unfortunately, when I tried to order the ratchet wheel I was told it is no longer available. Rats!. Then I remembered some small spur gears I had --- figured I could used the Dermel abrasive cutoff disk to shape the gear teeth to ratchet teeth. When I got out the Dremel tool bits I noticed the #199 high speed steel cutter ---- 3/8" diameter, 1/32" thick and 16 teeth --- on a 1/8" shaft. ***I found my ratchet wheel with shaft!*** (Interesting note: Hiraoka has a photo of using that very same Dremel cutter to machine a slot in his Heisler lubricator tank for the sliding cover. The photo is beside the diagram showing how he machines his ratchet.)

The 16 teeth vs. 40 teeth of Hiraoka's design will make the pumping 2.5 times faster. If the piston (plunger) is increased from 3/32" to 3/16", the output will increase by the square of the diameter ratio or about 4 times. So the combination of bigger piston and fewer teeth will increase output by 2.5 times 4 or a total of 10 times --- that's overkill. However, as I looked at all the areas where there can be slack plus the problems with getting the stroke of the piston exactly aligned with the feed holes in the side of the cylinder, I decided to go with this size. If it uses too much oil, I can file off the end of the piston, which will have the same effect as reducing the stroke.

The rest of the lubricator requires stock material except a steel ball --- 1/4" should be OK -- have some that I bought for the axel pump. Hiraoka specifies the spring for 1.5" scale as 7/32" OD, 9/16" long with 9 turns of 0.016" wire. McMaster- Carr lists a 1" long spring, 1/4" OD with 0.20" wire size, $5.74 a dozen. The fully compressed length is 0.28" so they must have about 14 turns. Close enough. (Later I found a nearly identical spring in an old spring assortment I bought years ago. I decided to use it.)

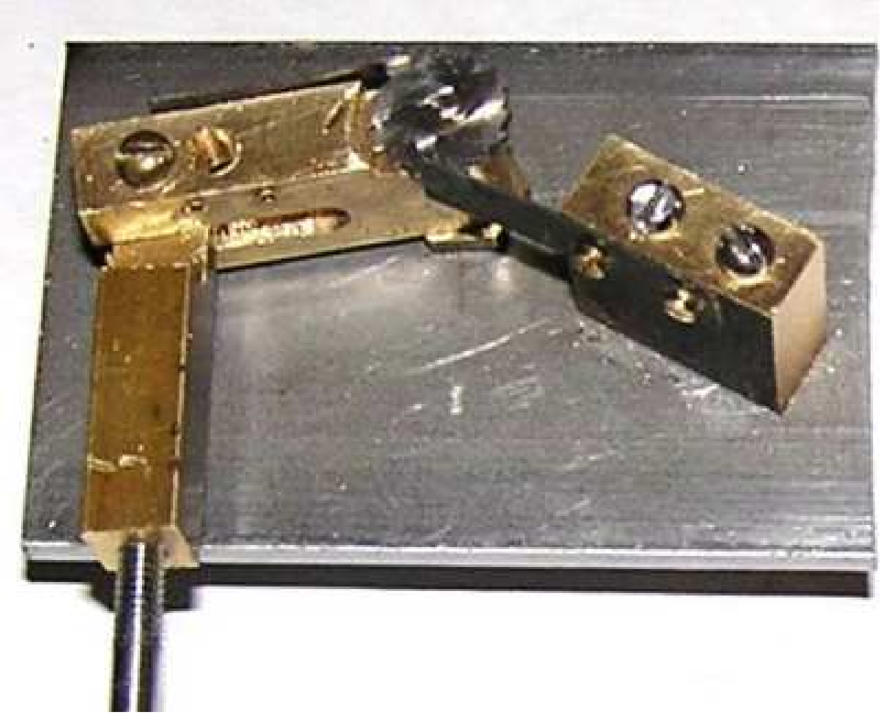
The next step was to figure out where to mount the lubricator. Kenneth mounted his on the right running board just ahead of the engine and drives it from the forward most valve mechanism. If I mounted my lubricator in the same spot, the ratchet wheel will be exposed and it's not going to be the nicest thing to look at since there was nothing like it on the prototype. Further, there is a protrusion out the bottom of the lubricator that contains the check valve spring and the outlet so I'd have to make a big hole in the running board. After looking at the alternatives for a few minutes I realized that it will mount nicely under that running board. The protrusion out the bottom would be no problem and the routing of the output pipe would be simplified. The ratchet wheel would be mostly hidden between the tank side and one of those triangle supports and the linkage to the eccentric would be short and direct. I'm thinking about a 2 inch square by 1.5" high tank. That size tank would set back 1" from the edge of the running board and be the same height as the frame I Beam. The tank can be attached to the side of the frame I beam

The last problem is a way to fill the tank. One thought is to just put a fill pipe up through the running board with a plug in the end. The plug could be removed to inspect the oil level. I'm going to have to think about that for a while.

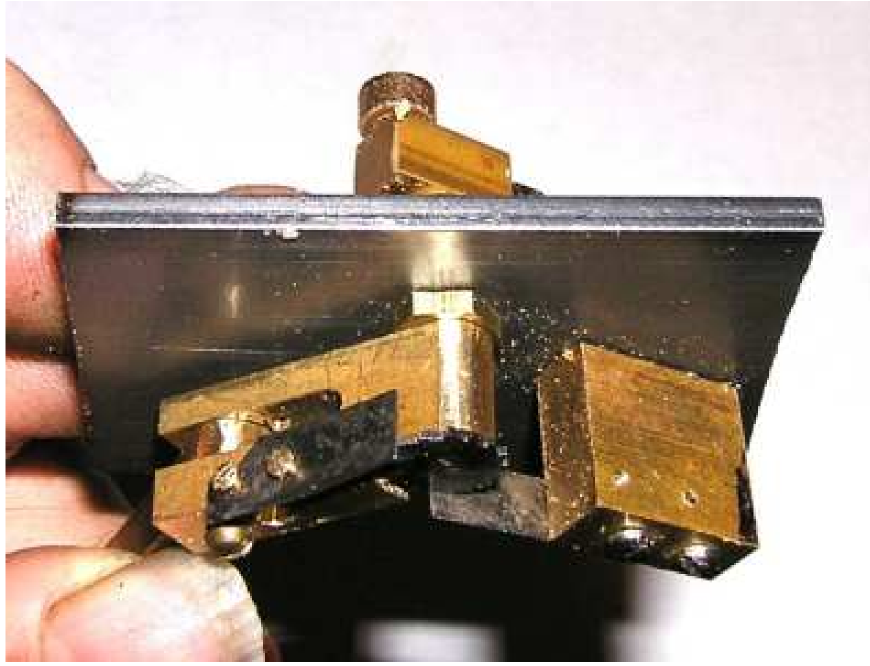
Drive Mechanism: The drive mechanism consists of the ratchet wheel, drive lever with spring paw, a fixed spring paw, a bearing and crank to drive the pump piston. Thought I'd start with the lever and then realized that the lever length had to be calculated.

The ratchet can be driven from the valve stem --- a link can be screwed into the lower end of the valve stem below the set screw that holds the link pin. The valve stem provides a lift of 3/8" The ratchet wheel has 16 teeth so the wheel must be rotated 22.5 degrees with each stroke. Recall that the arc length is radius times the angle in radians (aren't you glad you didn't sleep in math class). The 22.5 degrees converts to ~0.4 radians. So, the lever length to get 22.5 degrees from a 3/8" lift is .375" divided by 0.4 radians, ~0.094". At that length, we'll just make the required rotation assuming no float (slop) in the linkage. A lever half this length would rotate it past two teeth, assuming no float in the linkage. So, probably want a lever arm some place between 0.5" and 0.8" I'll make two settings, 0.6", 0.75" and then tune it up when installed. (A shorter radius was required for reliable operation as we'll see later.)

This shows the drive parts assembled on a piece of steel simulating the side of the tank. The **Ratchet Wheel** is easily recognized. The piece to the right of the ratchet wheel is the **Fixed Paw** which prevents the ratchet wheel from turning backwards (CCW). The parts in the lower left side are the **Link** and **Rod**. The piece to the left of the ratchet is the **Lever** which has a paw on the top



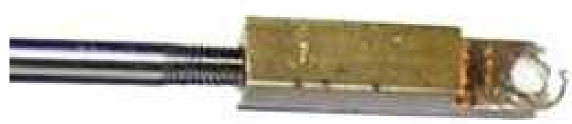
This shot taken from above shows the lever with the lever paw more clearly. The piece on the other side of the simulated tank wall is an early version of the **Crank.**

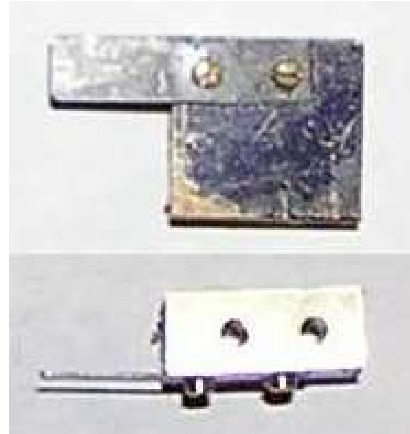


This is the **Ratchet Wheel** and **Shaft** made from the Dremel #199 cutter. The only modifications are that the shaft is cut to the correct length with Dremel cutoff disk (after assembly) and a flat is ground on the shaft for the crank setscrew. Note that the shaft is 1/8" except near the cutter where it is slightly larger.

The **Lever** rides on the cutter shaft above. The total width is 0.45" with the notch for the ratchet wheel about 0,050" The large width is so that part of the lever rides (rotates) on a smooth part of the shaft. The hole for the shaft is drilled and reamed 1/8" and the the outer part enlarged as necessary to clear the larger part of shaft near ratchet wheel. The lever is 1/4" thick and 1.1" long (later shortened). The slot is 1/8" wide with the holes for the pin located at radii 0.6" and 0.75" (third hole at 0.45" added later). The **Pin** is 1/8" drill rod drilled for a 2-56 screw. The holes in the lever are drilled 1/8" on the outer side of the slot and tapped 2-56 on the other side. The paw is described with the fixed paw.

The **Rod** is 1/8" steel threaded 5-40. The **Link** is a 1.1" length of 1/4" square brass. The end is drilled and tapped 5-40. The link fine adjustment is achieved by screwing the rod in and or out of link. The end that mates with the lever is milled to 1/8" thickness to match the slot in the lever. The hole in the end is drilled 1/8" to match the lever pin.





The base for the **Fixed Paw** is made from from a 0.6" square piece of 1/4" thick brass plate. (Please excuse the marking fluid I hadn't cleaned off.) The two mounting holes are drilled for 2-56 screws. Both the stationary paw and the paw on the lever are made from 0.008" thick spring steel. I didn't have any spring steel stock so used an old flat backed razor blade. Heated blade red hot and let cool to remover temper. The blade was then easily cut to desired shape and mounting holes (for 0-80 screws) drilled. The paws were then tempered by heating red hot again and then quenching in oil.

The **Bearing** is made from 5/16" hex brass stock. The end is turned 1/4" diameter for 3/8" length and threaded 1/4 - 28 leaving about 0.080" unthreaded to mount in tank side. The center is drilled and reamed 1/8" The piece is then cutoff the stock with a 0.090" hex head. The **Nut** is a standard 1/4-28 stainless hex jam nut I had left over from my Triumph parts.

This is the second version of the **Crank** and the one actually used. It is made from a 1/4" thick 3/4" diameter disk The crank is held on the shaft with a set screw. The crank pin is made from 1/8" drill rod. The crank pin is pressed into the disk and secured with a 1/16" roll pin inserted from the edge of the disk. The end of the crank pin end is turned down and threaded 3-48. crank pin is about 0.27" from the shoulder behind the washer to the disk.

Pump: The major piece of the pump is the pump body which contains the cylinder in the upper half and check valve consisting of ball and spring in the lower half. About one third the pump body is inside the tank, the other two thirds below. Half the cylinder is located inside the tank and severs as a guide for the piston. There are four holes in the side of the cylinder just above the the floor to allow oil to enter the cylinder. At the upper most part of the stroke the bottom of the piston is just above these holes. The piston stroke is about 0.275", most of which in below the floor. The cylinder bore must extend at least the 0.275" stroke below the holes. The ball check valve is at the bottom of the cylinder bore pushed up by a spring. There is a bottom plug to provide access to spring and ball. The output is through the side just below the ball.

With these data and the parts already made I was able to set some parameters as follows:

1. The pump cylinder unit extends 5/8" above the inside of the tank floor.
2. Assume the tank floor to be 1/16' (0.06") thick.

3. The oil input holes located just above the floor are 5/64"
4. The pump cylinder unit hangs down 13/16" below the floor (7/8" below the lower side of holes).
5. The cylinder bore extends 5/16" below the the lower side of the holes (this provides a little margin).
6. The bottom end is plugged with a 3/8-24 brass bolt
7. The output port is a 1/8" MTP threaded hole.
8. The cylinder unit is made from 3/4" brass rod stock
9. The cylinder bore is 3/16".
10. The part of cylinder inside the tank is turned to 3/8" and threaded 3/8-24.
11. A standard 3/8-24 nut is used to secure cylinder unit to tank floor.
12. The check valve ball is 1/4" diameter (had some).
13. The spring is ~7/32" OD and ~1" long.
14. The piston (plunger) is a piece of 3/16" drill rod.
15. The piston is cut long and will be trimmed as necessary after pump assembled.
16. The crank pin follower at the top of the piston is fabricated from 1/4" X 1/2" brass flat bar stock.

Then it was off to the workshop ....

I made the **Piston** (or plunger) first. (When making the upper part that mates with the crank discovered that the first crank version didn't work very well. The second version with the disk work better because it keep the follower straight.) The top (crank pin follower) is made from 1/4" thick brass. The slot is 1/8" wide. The slot is extra long to to allow for some misalignment between crank and pump cylinder. The piston is 3/16" drill rod silver soldered into the brass upper part. Note that the piston is offset so that the crank pin is centered over the the piston during down stroke --- this follows Hiraoka's design. The piston is too long at this point; it will be trimmed to the correct length later.

This is the **Pump Body** and associated parts.

The **Nut** is standard 3/8-24 stainless. The slots in the bottom are to allow oil to feed into the holes in the side of the pump body. The slots were cut with a Dremel cutoff disk. The inside of the nut near the bottom edge was enlarged slightly with a 7/32" drill to aid the oil flow to the oil feed holes.

The **Sealing Washer** fits between the shoulder of the pump body and the underside of the tank. It is made from nylon rod stock.

The **Pump Body** is turned from 3/4 brass rod. (I would have preferred to use 9/16" brass hex stock.) The top is threaded 3/8"-24. The bottom of the 5/64" oil feed holes are even with the tank floor. The cylinder through the center of the body is drilled and reamed 3/16" The inside of the lower part is threaded 3/8"-24 for the plug. The short distance (~.2") between the bottom of the cylinder and the 3/8" threads (for the plug) was bored to ~9/32" with the top flat to make a good seat for the ball. Before assembly, the ball was put in position and then tapped with a punch to make a seat. The side port is threaded 1/8" MTP and has a short nipple screwed into it.

The **Ball** is 1/4" steel.

That **Spring** is 7/32" OD and a little over an inch long -- from the scrap box.

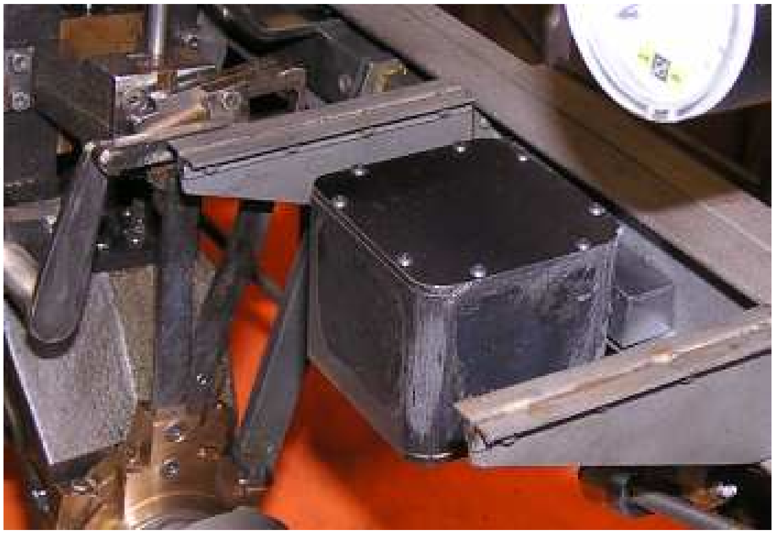
The **Plug** should have been made from 9/16" hex stock. I didn't have any so I drilled out a 1/8" pipe cap and silver soldered in a brass rod and then machined it into the plug. The black thing is a sealing washer make from a scrap of Delrin rod. The plug is drilled 1/4" on the inside for the spring.

Tank: The tank is made from a scrap piece of 3/16" wall 2" square tubing obtained from the local machine shop. The tank is to be 1.5" high so I sawed a slightly longer piece and then used the mill to square up the ends. The bottom is14 gauge steel plate. I cut the bottom extra big so that I wouldn't have to worry about perfect alignment when silver soldering it to the tube. The photo shows the two pieces just before soldering. Those are strips of silver solder on the bottom. The with stuff is flux. (The area of bottom plate that will be soldered was sanded to remove the scale.)

This shows the pieces in position to be soldered. That's a piece of scrap steel used for a weight. After the pieces were soldered and cooled the bottom was trimmed. I first used the band saw to trim off most the excess. I then cut the remaining excess down with the bench grinder and used a file for the final finish. A machinist might cringe at this technique, but it works for me.

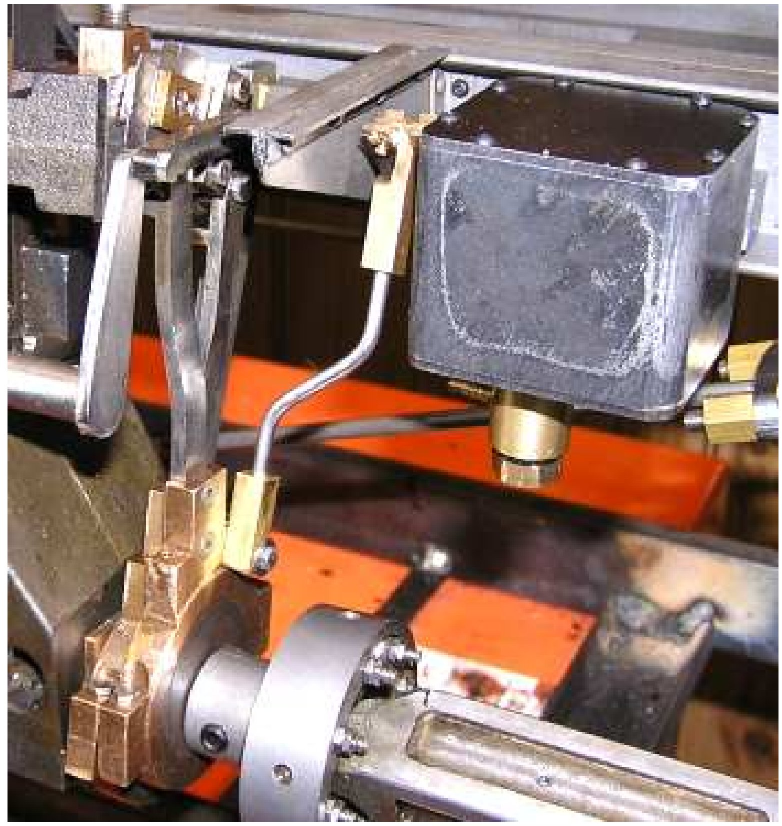
I did a better job of making the top. I first sawed it on the band saw and then used the mill to square up the edges and get within about 0.20" of the final size.

The next step was to drill mounting holes in the top, clamp the top in position and use the top as a pattern to drill and tap the holes in the sides. After the top was screwed in position, the final trimming of the top was done with a file. Photo shows the tank at this point. Looks so good, hate to hide it under that running board.



A piece of 1/2" square bar is attached to the back of the tank with 6-32 screws. The bar is positioned such that the tank is the correct height when the bar is resting on the top of the bottom lip of the frame I beam. The tank is held to the I beam by two 6-32 screws into the square bar. The tank is positioned such there is room for the lever and ratchet mechanism between the tank and the bracket to the rear of the tank.

Assembly: The assembly was straightforward: drill holes for pump body, bearing and the screws that hold fixed paw. Next, mounted the unit to the frame and worked on the linkage. After several attempts, the design was changed by drilling another hole in the lever arm to make the lever shorter and the position of the lever arm and fixed paw were reversed --- the lever is now at the front. I then made a link from the lever to the lower screw that connects the link blade to the eccentric strap. That worked pretty well but the adjustment was touchy to make the lubricator work when the eccentric strap was changed from forward to reverse.



This shows the attachment point that works well ---- the position of the lever is the same for the eccentric strap set for either forward or reverse. I think this works because the attachment point straddles a line from the link pin to the center of the crank shaft --- in forward the attachment point is to one side the line and in reverse an equal distance to the other side of the line.

The pin at the lower end of the link is made from 3/16" drill rod with a 4-40 screw (washer under screw head) holding the hollow pin to the eccentric strap.

This shows the modifications of the lever and fixed paw. The lever pivot is at a radius of about 0.45" and gives considerable margin without advancing two teeth at a time. The lever length was reduced so the end wouldn't hit the running board. I've broken several sets of paws made from razor blades so will get some spring steel the next time I order something from Coles. Maybe when I make new paws I'll also make a new lever that doesn't show the modifications. The screw in the tank just to the right of the lever plugs one of the holes that was used to attach the fixed paw when I had the paw and lever reversed.

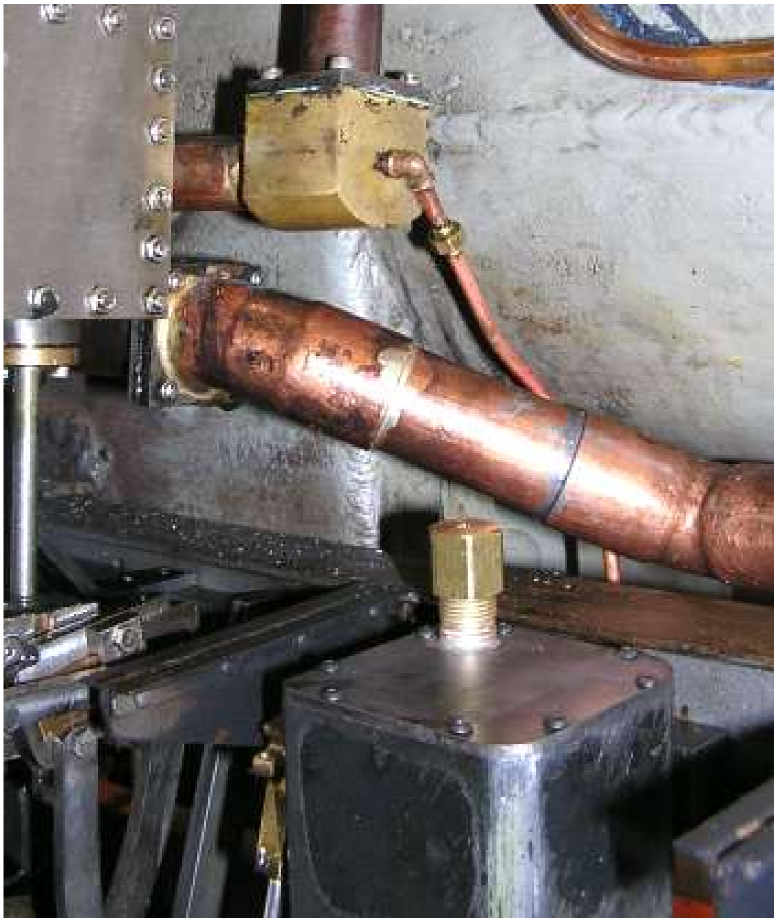
This shows the inside of the assembled unit.

I wore out my old camera (Olympus D510) --- it's away to be repaired on the four year warranty I paid extra for. If they can't fix it they will give me a new one. Since I have another trip coming up I decided to buy a replacement in case I don't get the D510 or replacement back before leaving. This one is an Olympus C740. It's the old model now so is available at reduced price. It takes great close ups (as seen here) and has a neat lens. It's not as rugged as the D series. I will be happy to get that one back to take on the trip --- the D series slips in the pocket and is great for the hiking I do in the mountains and jungles. However, I will now be using the C740 for photos of the Shay.

As you see ----- there were a number of changes in the project as I went from conception to the running unit. This is normal; that's why engineers and designers use laboratories. (It's also frustrating at times.) The Dremel cutter worked great for a ratchet wheel. Other possibilities are small diameter slitting saws and small woodruff key slot cutters. The next time I'll use 9/16" hex stock for the body. The part of the pump body that hangs below the tank can also be made 1/4" or so shorter. If I had only two cylinders (thinking of a Climax or Heisler) I'd probably go with 5/32" piston and 7/32" ball. That would allow the threads on each end the pump to be reduced to 5/16" and, in that case, I'd use 1/2" hex stock for the body. As noted, the razor blades don't hold up very well ---- they became too brittle and break easily. Will order some spring steel and replace the paws before I have to really depend on the pump. Some vendors sell powder coated lubricators; that sounds like a good ideal for the tank. In fact, I plan to powder coat much of the Shay. (Home powder coating is easy, see: http://www.buckeyetriumphs.org/technical/PowderCoating/powder_coating_equipment.htm)

I tested the pump and it does in fact work -- a drop dribbles out every rotation of ratchet. When I covered the 1/8" output nipple with a finger, I could feel two pulses every stroke --- two notches to push piston down. It looks like maybe too much oil. If so, will shorten the piston a bit. The next test will be to see if it can push against the steam pressure. That must wait until the boiler arrives and inlet header is finished. Must also decide on a oil fill port. Will revise this note when those additions are made.

Update 12/12/03: A 1/8" tube was connected from the pump output to the end of the engine input header. A union was put in the line near the header to facilitate lubricator removal. The photo at right shows the upper end of this tube.



A 1/8" pipe nipple was silver soldered to the top to serve as a filling tube. The cap is a simple pipe cap with a 1/16" hole drilled in the center.

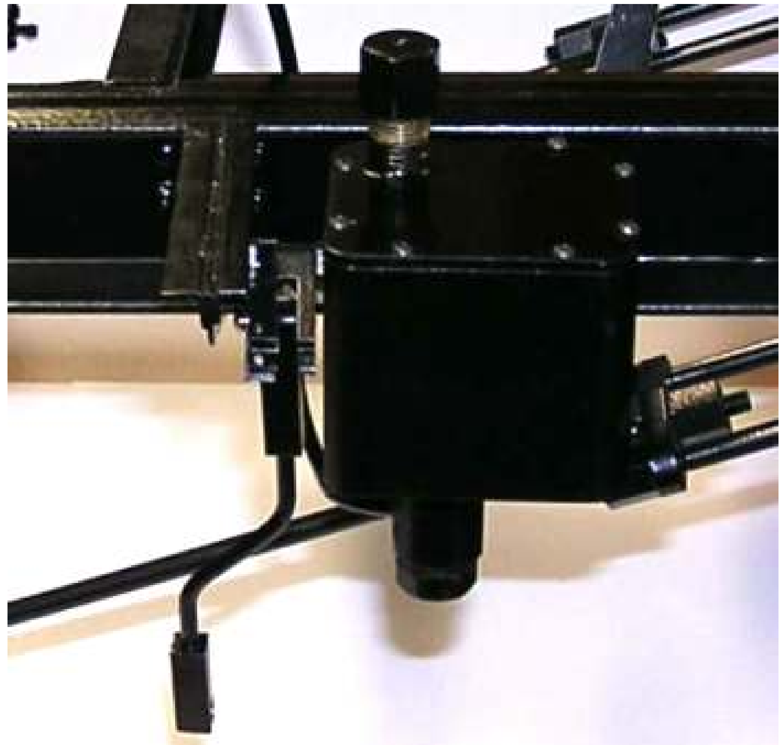
Initial tests of the lubricator (using compressed air to power the engine) indicated way too much oil was being supplied. The piston stroke below the bottom of the feed holes was measured to be 0.25". The piston was shorted to reduce the stroke to about 0.1". After a test run on steam the piston was shortened again to make the stroke about 0.050". This cut the consumption to about 0.25 fl oz per hour. The ~2 fl oz tank should last all day.

It is now clear that a 1/8" piston diameter is a better match for the 12 tooth ratchet.

Update 2/29/04: Before painting the lubricator I thought I'd better try to figure out why it was putting out so much oil. (Initially when it was running it on compressed air, the oil coated the smokestack and was running down the outside. When shut off, the oil dripped down around the flange on the bottom of the smokestack. If powered by steam, the oil would have probably mixed with the steam and been dripping off the engineer.) Initially, the stroke was a little over 0.25". As pointed out above, the consumption is now in the ballpark after the stroke was cut to ~0.050". The output was expected to be maybe twice the appropriate oil, but not 3 or 4 times. How could it have been off so much? The calculations were checked again and all seemed to be in order. Then it dawned on me ----- **Hiraoka's pump runs on an axel and I'm running the pump off the crankshaft ---- the crankshaft turns twice as fast as the axel hence twice as much oil!** Hence, about 4 times the required oil.

Even with the stroke cut to ~0.050", it's still probably pumping a little too much. The stoke is so short that it can't be trimmed any more without running the risk of the no oil being pumped. So, I bit the bullet and changed the piston to 1/8" by sawing off the old piston, drilling the stub in the follower and silver soldering in a 1/8" diameter rod. A plug was silver soldered in the cylinder bore and the plug was then drilled and reamed 1/8" The whole job took about an hour. The stroke below the input holes is now about1/8". This will probably pump a little more oil than before but will give plenty of room for adjustment if needed after a real test pulling a load on a track.

The lubricator was powder coated before reassembly. The photo shows the mounted lubricator. Took the opportunity for a photo before it's partially hidden under the walkway.



Update 6/6/04: Several problems with the lubricator showed up on the first few test runs::

- The 1/8" filler pipe was too small --- the oil stuck to the side plugging the pipe making it impossible to fill.
- The 1/8" MTP union connecting the lubricator line to the steam header was too difficult to connect and disconnect.
- The check valve failed again allowing steam to back up into the lubricator.

The input pipe was changed from 1/8" pipe to 3/8" pipe, which made it very easy to fill.

I did a bit of research on manufactured lubricators and found that Loco Parts makes a lubricator check valve combined with a right angle fitting that connects to the steam chest. This fitting is 1/8" NPT on the steam chest side and 1/8" tube compression fitting on the input side. I also noticed that some of locomotives at MCC had an external check valve in addition to the one in the lubricator so others may have had the same check valve problems.

One concern with using a 1/8" tube compression to 1/8" NPT elbow at the stream header was that the 1/8" pipe size would seem way out of scale on the little shay. I found a 1/8" tube compression to 1/16" NPT elbow at McMaster-Carr --- part # 5053K57. This fitting is sold as "quick assembly" and comes with a combined compression nut and sleeve. The standard nuts and sleeves will also work with the elbow. Note that 1/16" NPT is the same thread as 5/16" MTP ---- buy the 1/16" NPT taps and dies, they are 20% the cost of the MTP taps and dies.

I decided to switch from steel balls to poppet type check valves using O-Rings to see if they sealed any better. The Buna N O-Rings were selected because they are compatible with oil. The 250 degree max temperature will be OK at the lubricator end but will be pushing it at the steam header end. If the O-Ring at that end fails I'll replace it with a Viton O-Ring.

For the lubricator end, the #103 O-Ring (3/32" ID, 1/16" cross section) was selected along with a 5/8" long 0.24" OD, 0.026" wire size stainless steel compression spring. Both McMaster-Carr and MSC sell packages of 5 precision compression springs for less than $5. The one used here is McMaster part number 9435K39 which they list on the website for $9.73. When the item is added to the shopping cart it shows up as $4 something. Recall that the lubricator was originally made with a 3/16" bore and the bottom part with the check ball was drilled 5/16" and tapped 3/8-24. Later, the upper part of the bore was sleeved and reduced to 1/8" to reduce oil output. If the lubricator was originally designed for 1/8" bore then the smaller poppet made for the steam header end would also be suitable for the lubricator end.

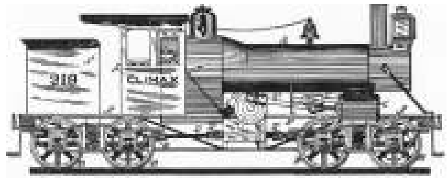
The # 003 O-Ring (0.056" actual ID, 0.176" actual OD) and a 1/2" long 0.18" OD, 0.018" wire spring (McMaster # 9435K24) were selected for the steam header check valve.

Lubricator Poppet: This photo shows the lubricator poppet. That is a #4 stainless screw with nut and #3 washer. The nut and washer were silver soldered in place. The filister head was ground down such hat it fits in the bottom end of the original 3/16" cylinder bore. The excess screw length was later cut leaving a ~ 1/4" long stub to fit inside the spring.

Steam Header Check Valve: This photo shows the parts that make up the steam header check valve. The poppet is made from a #2 screw nut & washer. The nut and washer are silver soldered to the screw. The brass part next to the elbow is the 3/16" OD 5/64" ID valve seat. The elbow was drilled out to 3/16" and the seat silver soldered in place at the bottom of the hole. After soldering, the joints were cleaned up with 5/64" and 3/16" reamers. The 1/16" brass pin on the left was used to retain the spring after assembly. The ends of the pin were trimmed flush and a die was run over the threads.

Installed Elbow with Check Valve: This photo shows the elbow with check valve screwed into the end of the steam header. The elbow was painted so it fits right in. The compression fitting on the 1/8" tube is much easer to connect than the 1/8" MTP union.

I've had about 8 hours operation with these poppet valves and no more trouble.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