Plumbing Part I - General Plan

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While I've been busy building the mechanical parts of the locomotive I've also been thinking about the plumbing --- and there's a lot of plumbing on a steam locomotive. Most the mechanical parts are now done so it's pretty clear I'll have to start the plumbing soon. Kenneth provides drawings for some of the plumbing components such as the pumps and steam manifold, but he doesn't provide drawings for entire plumbing system. I've been collecting data over the past months and also had a long chat with Ken about the plumbing. I spent much of June doing volunteer training in west Africa. The long flights and lonely evenings presented a good opportunity to organize a "plumbing plan" so I loaded all the data on the notebook computer before leaving. Thinking about the plumbing made the flights go quickly as well as some of the evenings where I wasn't preparing for class. The following is the plan. As with most plans, things will change so I'll try to come back and update the plan from time to time.

Joining Pipe and Fittings: There are several ways to join pipes:

- Soldering joints (sweat joint)
- Compression joints.
- Threaded joints.

I'd already using solder joints on the copper pipe to make the engine steam inlet header and exhaust manifold. Silver solder was used on these joints since they carry steam ---- regular soft solder melts at about 350 degrees F and should not be used on steam joints since the 100 psi steam is also at about 350 degrees F. I plan to get some of the tin/silver soft solder that melts at about 550 degrees to use on some of the plumbing fittings.

Compression fittings work quite nicely for tubing but are not to scale.

Threaded joints were used for most pipe fittings on the prototype. These threads (called NPT in US) are tapered to make a pressure tight seal. (Some suppliers sell fittings that use straight threads. Straight threads will not seal, even with pipe dope; they must be soldered to seal.) Kenneth suggest using Permatex Form-A-Gasket No. 2 for sealant on tapered pipe threads.

Scale Pipe: Most the pipes for a 1.5" scale steam locomotive are in the range of 1/8" to 3/8" OD. Smaller sizes of regular household brass pipe fittings can be used but the wall thickness is out of scale as are the valves, unions, elbows, etc. The 1/8" and 1/4" sizes are closest to scale. (Note, as shown in the table below, the dimensions of plumbing pipe in not directly related to the pipe size --- confusion!)

Copper tubing is available in OD sizes 1/8", 5/32", 3/16", 1/4" and 5/16" that make excellent scale pipes. Tapered taps and dies called Model Taper Pipe (MTP) are available to cut male and female threads for this tubing. Scale fittings such as valves, elbows, tees, unions, etc that use the MTP threads are also available. The MTP taps and dies cost $36 each, a substantial investment, especially if several different sizes are used. The 5/16" MTP is the same as 1/16" NPT so one can purchase the 1/16" NPT taps and dies and about $25 on each.

Selected Pipe Sizes: Kenneth limited the number of sizes of pipes he used. He used 1/2" and 3/4" L type copper pipe for the steam pipes to and from the engine. He used 1/8" and 1/4" tubing for most water and steam piping. Some 1/4" and 1/8" regular brass pipe were used in some special situations. I decided to follow Kenneth's lead here with the addition of 3/16" tubing. Data on these pipes plus 5/16" are shown in following table.

Size	OD*	ID*	Joints	Use
1/8" Tube	1/8"	0.061"	Compression/Solder/ MTP 1/8-56	General steam
3/16" Tube	3/16"	0.124"	Compression/Solder/ MTP 3/16-40	General steam
1/4" Tube	1/4"	0.186"	Compression/Solder/ MTP 1/4-40	General steam & water
5/16: Tube	5/16"	0.216	Compression/Solder/ MTP 1/4-40	Shown for comparison
1/8" Pipe	~0.41"	~0.25"	NPT 1/8 -27	General steam & water
1/4" Pipe	~0.54"	~0.375"	NPT 1/4 - 18	Boiler & Throttle
1/2 " Type L Tube	5/8"	0.545"	Solder	Engine Steam Inlet
3/4" Type L Tube	3/4"	0.785"	Solder	Engine Steam Exhaust

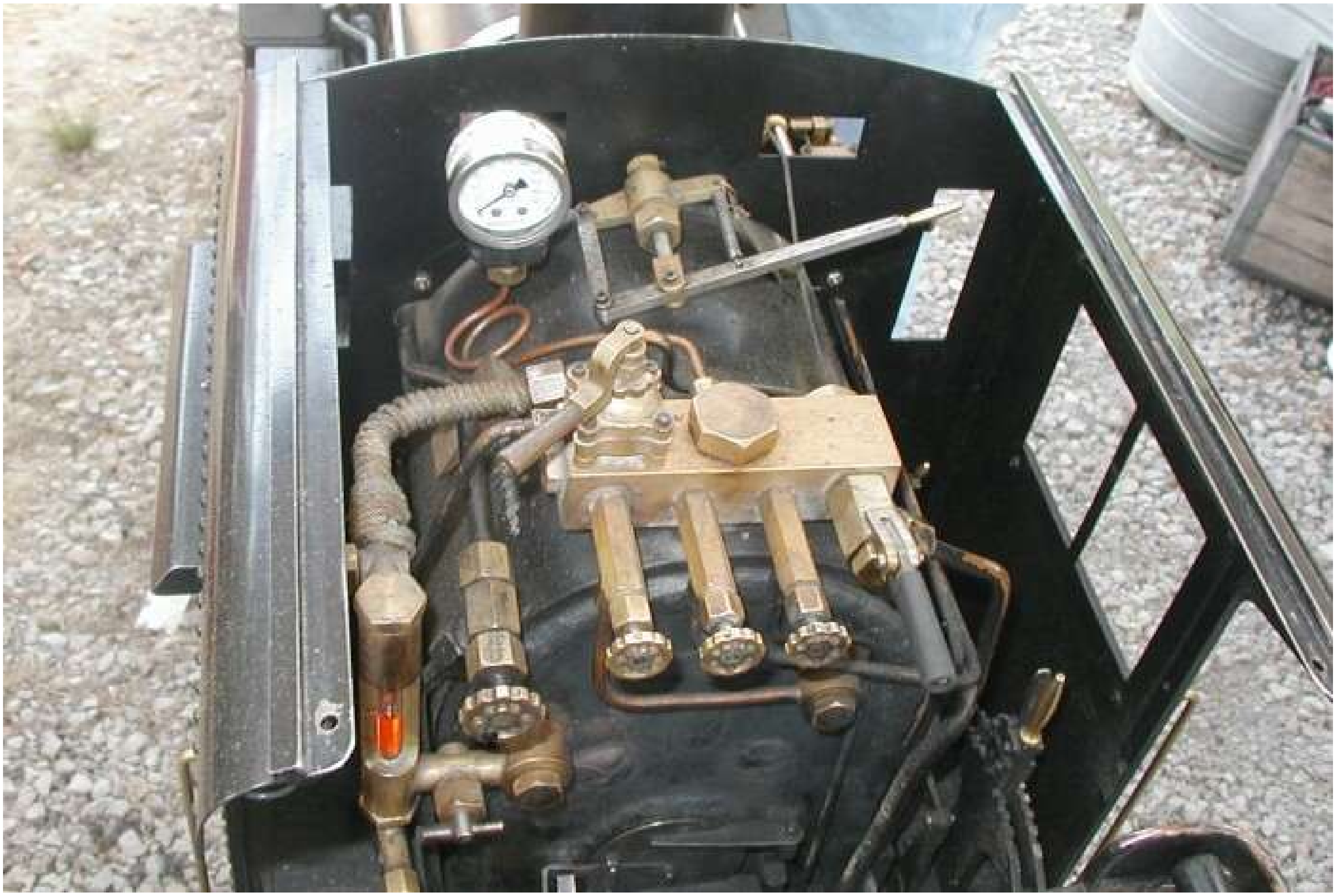
*** Tubing OD/ID:** For MTP threads Coles suggests 24 Ga -.022 for 1/8" OD tube, 20 Ga - 0.35 for 3/16" and 1/4" and 18 Ga - 0.49" for 5/16". I plan to use 0.032" hard tubing from McMaster-Carr for 1/8", 3/16" and 1/4". McMaster- Carr carries 5/16" hard copper tube in 0.032" wall and brass tube with 0.62" wall. The 0.032" wall is fine for sweat and compression joints but not MTP, the 27 TPI threads are too deep for that wall thickness. On the other hand, the 0.062" wall 5/16" tube has the same ID as the 0.32" wall 1/4" tube. McMaster-Carr carries rolls of soft 5/16" tubing with a 0.049" thickness that matches Cole's suggested thickness. (Ken Schroeder said he buys a roll of the soft tubing and stretches it between a couple of trees with a come-along and then cuts the straight tube into convenient lengths for storage.) The message is that the courser 5/16" MTP thread requires a thicker wall and some of the gain of the increase in OD going from 1/4" is lost due to the greater wall thickness.

Fittings: The scale fittings look really neat and so I decided to use them wherever possible on visible plumbing. I'm aware of four brands of scale fittings: TrueScale, Super Scale and LS Manufacturing and PM Research. TrueScale is sold by Coles while the other three sell direct (see links). Super Scale fittings are more expensive and in many cases have better detail. However, many of the Super Scale fittings such as elbows and tees are 50% more expensive than the TrueScale counterpart but are unthreaded while the TrueScale parts are supplied with threads. The Super Scale LS unions have hex ends like the prototype whereas the TrueScale unions have round ends that make it difficult to tighten and loosen the union. LS Manufacturing carries only 1/4" fitting at the present time. The LS valves and unions have excellent detail at what they say is an affordable price. PM Research has a line of cast valves, check valves and fittings. The PM Research 1/4" and smaller fittings use straight threads while the 5/16" are tapered. PM Research also offers unmachined castings including a very economical tree of nine fitting castings. There are photos of the various fittings and valves from different manufacturers in the Plumbing V - Fittings webpage.

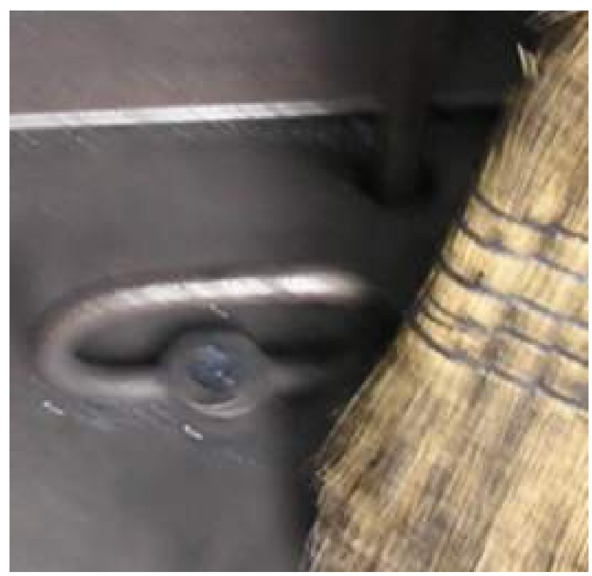
For parts that are not visible such as in the water tank and under the floor boards I plan to use 1/8" pipe and 1/8", 3/16" and 1/4" tubes with compression fittings. This is primarily to minimize cost. However, the compression fittings are convenient to use because they can be disassembled one joint at a time similar to a union.

Valves: Many modelers make their own valves. I decided to purchase nearly all my valves. I'll use scale parts for the visible valves and regular 1/8" plumbing valves for those not visible such as under the floor.

I did however decide to fabricate the brake, whistle and blowdown valves. Last spring I met Jim Buchanan (see Buchanan Machine Works) and had a chance to closely examine and photograph his Class B Climax. The entire locomotive is a first class job. Since I was thinking plumbing at the time I was particularly interested in how he did these functions. I really like the way he attached the brake and whistle valves directly to the steam manifold as shown in the photo below. The brake valve is similar to a design in a earlier Live Steam article that Jim was kind enough to copy for me. I'll have more to say about these valves as I make them.



Blowdown Valve: Jim Buchanan also sent a copy of a neat design for a blowout valve. I had never seen the blowdown valve on a Shay so on a subsequent trip to Cass I looked really closely and found that the location the same on four of the Cass Shays I examined: at the bottom rear of the mud ring, directly below the firebox door. The next photos show the blowdown valve on Cass No 5 on the left and the valve operating handle on the right (sorry about the blurred photo). The handle is on the cab floor directly behind the boiler and to the right of the firebox door.



Firing with Oil: I've decided to fire the locomotive with oil. Propane is clearly the best choice in terms of clean burning, total heat output and ease of use. However, propane requires a substantial car such as a boxcar to carry the two propane tanks. I want to be able to run the bare locomotive or the locomotive with a few log cars --- like the prototype. I selected oil rather than coal because I didn't want to be both the fireman and the engineer.

I plan to use an oil burner like that described in the May/June Live Steam --- Part 12 of Three-truck Climax. This burner seems to be a slightly modified version of the burner described in So You Want To Build A Live Steam Locomotive. The burner mixes steam with the oil to atomize the oil. This presents a problem when starting the burner with no steam pressure. I plan to have an arrangement to supply compressed air until the steam is up to operating pressure. A draft mechanism is also needed to get the fire going until pressure is built to the point so that the blower can create the draft. Compressed air can also be used for the blower. This led to the conclusion that the plumbing should be setup so that the steam manifold could be pressurized by either steam or compressed air ---- a dual system.

Dual Air-Steam Manifold: As just pointed out, there are several advantages to being able to pressurize the steam manifold with compressed air until steam pressure is developed. One could merely connect the entire boiler to compressed air. However, I was advised against that because it would force oxygen into the water which could increase corrosion. Jim Buchanan mentioned that if he were to do another steam locomotive he'd put a cutoff valve between the boiler and steam manifold so that he could cut the pressure off to the manifold to do maintenance without taking the boiler pressure down. This led to a design where the steam manifold is fed from one end by the boiler and the other end by compressed air with a cutoff valve in each feed. The boiler feed will be via 1/4" pipe and probably have an angle cutoff valve in the boiler fitting. The air input will be 1/8" pipe with a cutoff valve and air hose male quick connect under the floor on the right side --- about under the Johnson Bar.

The steam manifold will have the blower and burner atomizer valves. There will also be at least three extra ports for future expansion. The brake valve will mount on the top of the manifold. I'll also want to incorporate the whistle valve in the manifold similar to what Jim Buchanan did -- will have to figure that out later.

Update: Turns out that I made a steam turret on top of the boiler and a manifold along the right side of the backhead for the blower and atomizer valves. The manifold is plumbed to both the compressed air input and the boiler with valves to keep the compressed air from entering the boiler. I didn't put a cutoff valve between the manifold and the boiler and I didn't mount the brake valve on the manifold. .

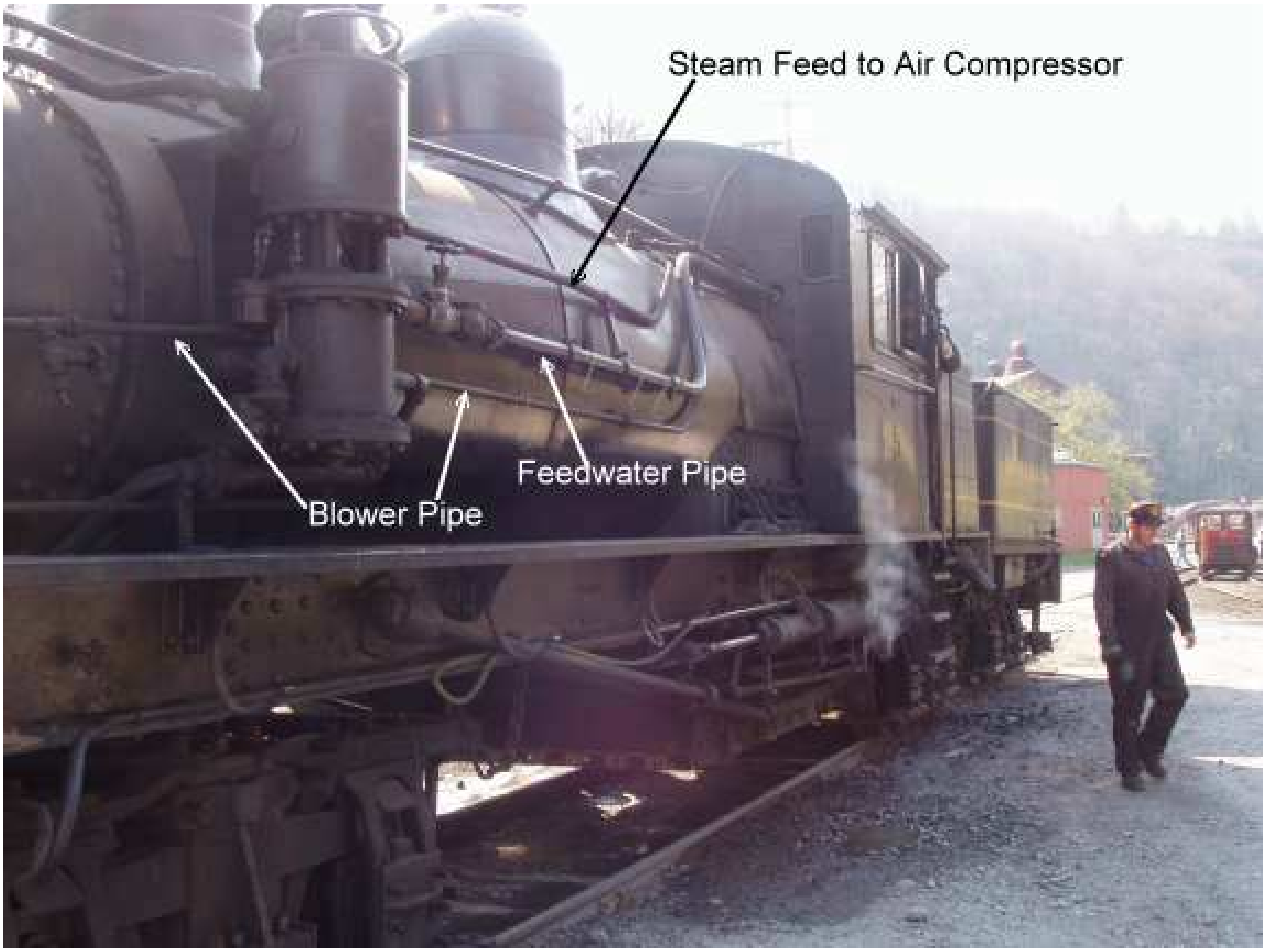
Pipe Routing and Mounting: The major concentration points for the pipes and fixtures are in the cab around the end of the boiler and under the cab floor. The plan is to secure the plumbing hardware to the boiler and/or to the under side of the cab floor. The cab floor, cab and fuel tank will be removable without disturbing the plumbing. Unions will be used in all pipes from under the floor or through the cab front to other parts of the locomotive to allow disconnection of these pipes.

Water Gauge: I had originally planned to make the water gauge but later decided to use Coles' "water gauge for large boilers" The bottom part of this gauge screws directly into the boiler. The top of the gauge will connect via a union and cutoff valve directly to the boiler rather than through the steam manifold. Jim Buchanan mentioned that he moved the top connection of his water gauge from the steam manifold to a separate feed because operating the whistle and/or blower caused a pressure drop in the manifold and an incorrect reading on the water gauge. I'll also connect the pressure gauge to this second port in the top of the boiler.

Hand Pump Feed Water System: The hand pump is located in the water tank and serves as a backup for the axel pump. The output of the pump is 1/4" tubing. The output is under the tank near the right side where it feeds into a 1/4" ID hose. The other end of the hose terminates under the fuel tank between the main frame sides. From there it runs in 1/4" tubing under the floor and then up through the floor on the right side of the boiler. It exits the front of the cab above the boiler mid point, bends down and follows the middle of the boiler. Near the front of the boiler it runs through a union, a check valve and a globe valve and then into the boiler. This routing is similar to Cass No 5 shown in the photo further down.

Axel Pump Feed Water System: The axel pump is located on the middle truck. A low pressure water supply line from the tender tank is located opposite the high pressure feed for the hand pump. This low pressure feed also connects via 1/4" ID hose to under the fuel tank, on the left side. This then goes into 1/4" tubing secured to the inside of the frame. A tee in this line connects to 1/4" ID hose to feed the axel pump input. The other side of the tee runs to the left side of the boiler and up through the floor. The output of the pump is 1/4" ID hose and then into 1/4" tubing where it runs under the floor to the left side of the boiler and then up through the floor into a tee inside the cab. One side of the tee connects to a pipe that goes through the front of the cab and then down the left side of the boiler through a union, check valve and valve and then into the front of the boiler, identical to the feed from the hand pump on the right side. The other side of the tee feeds into a second tee with a valve on each leg of the second tee. One valve connects to a short drain pipe and is used to bleed of air as well as verify that the axel pump is in fact working. The second valve connects back to the low pressure side of the axel pump and is used to reduce the amount of water feed to the boiler.   This entire system uses 1/4" tubing.

Blower: The blower line runs from the blower valve on the steam manifold down the left side of the boiler under the feed water line and then into the left side of the smoke box. This line was initially planned for 1/4". However, after looking at the following photo of Cass No 5, I decided that the blower line should be smaller than the water feed line.   Since the water feed line is 1/4", 3/16" was selected for the blower line. (The 3/16" tube with 1/8" ID will be more than adequate to supply the blower ring that has four 1/32" exit holes.)   That's a Murry Mercier photo taken on a foggy April morning.



Fuel Feed Plan: The fuel feed is hidden under the floor. The feed runs from the tank through a cutoff valve to a tee. One side of the tee goes to a drain valve. The other side of the tee goes through a fuel filter into a fuel metering valve.   The metering valve is under the floor with the handle above the floor. Everything from the fuel tank to the metering valve is 1/8" pipe. After the metering valve it converts to 3/16" tubing, runs along the right side of the fire box and then across to the burner in the middle of the front of the firebox.

Update: The fuel tank metering valve was mounted inside the tank with the control on the top. A separate drain valve with valve was also provided.

Atomizer Line: I haven't got this line worked out yet. The valve will be in the steam manifold. I want to put a pressure gauge in the line to be able to keep the pressure in the 5 psi to 25 psi range which means I want a gauge with maximum pressure about 50 psi. I probably want to put a pressure relief valve in this line to prevent damaging the gauge if the line plugs or if the valve is opened too far. At this point I think I'll run from the valve to a tee with the gauge on one side and the other side going through the floor on the right side to a tee under the floor. One side of that tee can go to the pressure relief valve set for about 50 psi and the other side feed 3/16" tubing that parallels the fuel feed to the burner valve.

Update: The atomizer pressure regulation problem was solved by using a small regulator.

Steam Brake: A steam brake valve similar to that shown on Jim Buchanan's Climax above will be located on the right side top of the steam manifold. The output of the valve will be 3/16" tubing that splits near the cylinder into1/8" feeds to each end of the cylinder.   I haven't figured out this routing yet.   There will need to be a drain cock or two in the line under the cylinder to drain off condensate.

Update: The brake valve was mounted on the shelf above the rear engine cylinder.

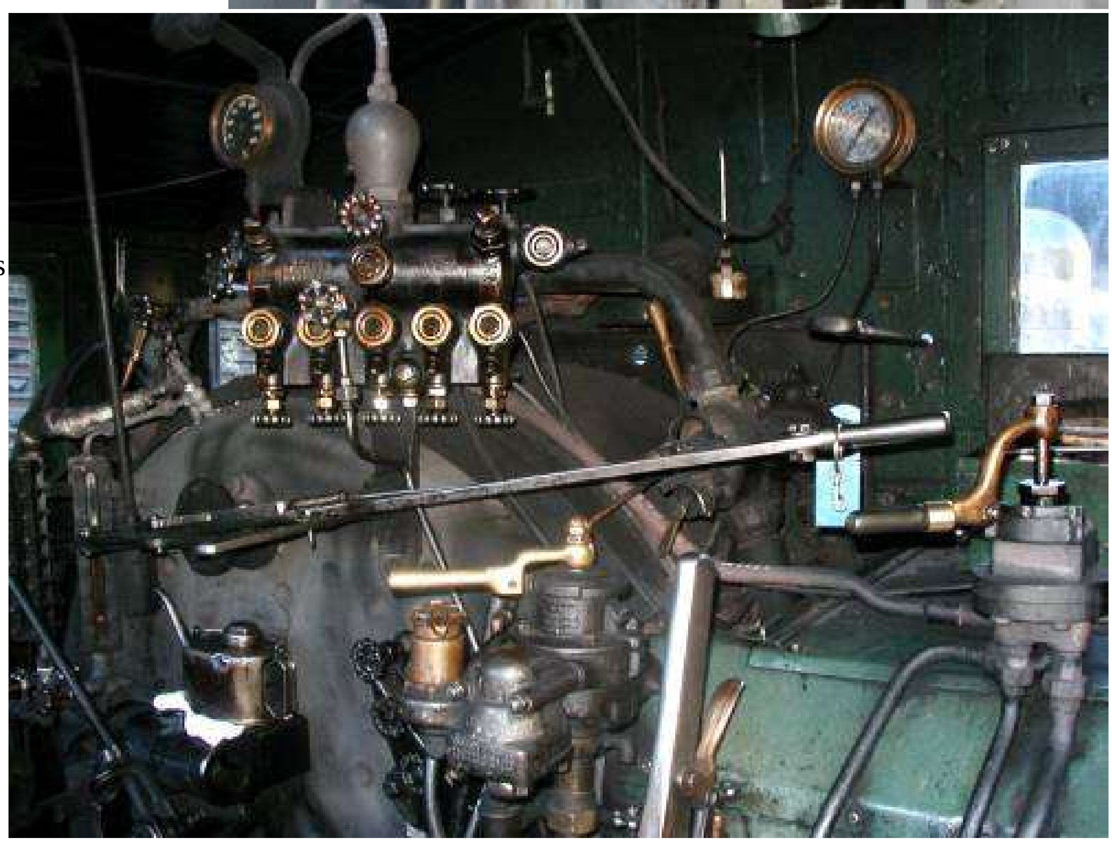
Whistle: Haven't thought much about this yet. Kenneth locates the whistle on the right side running board where it resembles an air tank. That sounds like a good scheme. I'll put the valve on the steam manifold. Don't know about tubing size yet.

Update: The whistle valve was located on the shelf beside the brake valve.

Lubricator: The mechanical lubricator pump will be located under the right running board just in front of the engine. It will be driven by the most forward valve eccentric. The lubricator output is 1/8" tubing that feeds the forward end of the engine input manifold.

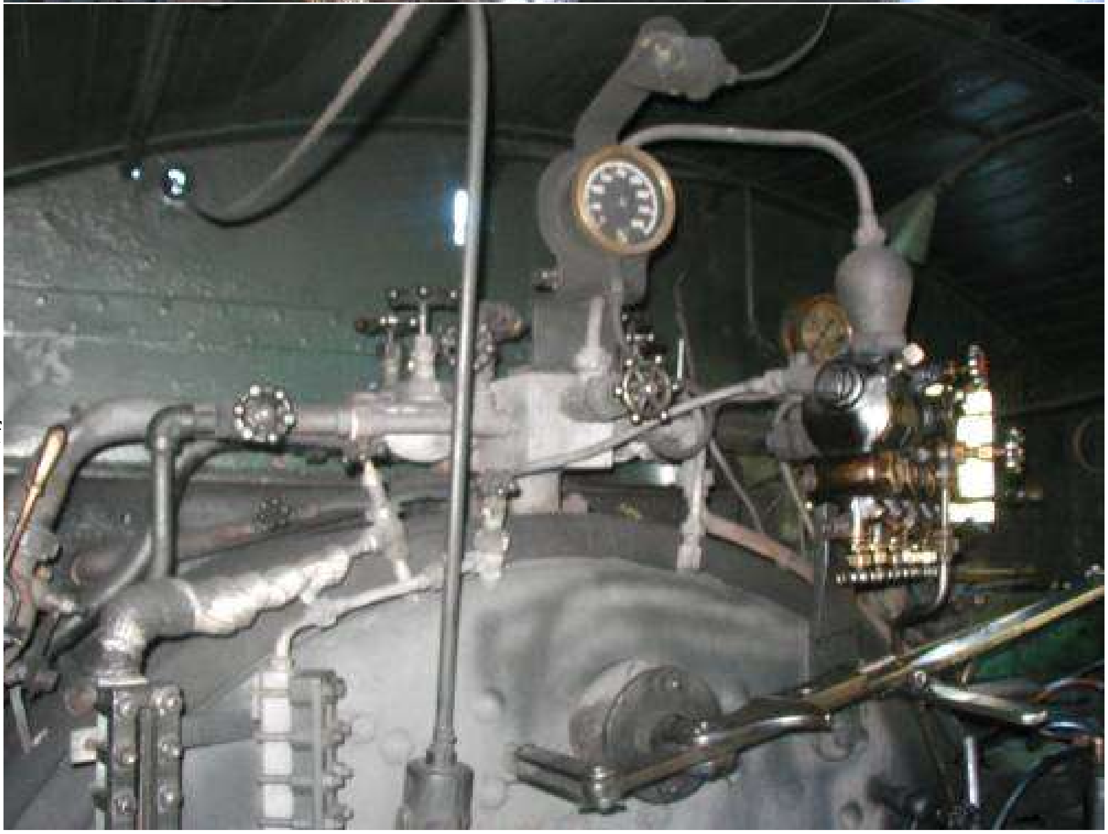
Cylinder Cocks: The holes for the cylinder cocks were initially drilled and tapped 4-40 and plugged with screws. The plan is to make cylinder clocks following the technique Kozo Hiraoka describes in Building the Climax. It would be nice to have all 6 cocks ganged together like on Cass Shay No 5 shown on the right.

Cass 5 Cab Interior: The following are some photos of the interior of Cass No 5 (80 ton Class C built in 1905). This gives some idea of the plumbing on the real thing. This first photo shows the right side of cab with two brake valves (one steam, one air) and throttle. The unit at top of boiler with 5 valves on the bottom I think is a lubricator --- of the displacement type I assume. That's the long throttle lever above the two brake valves.

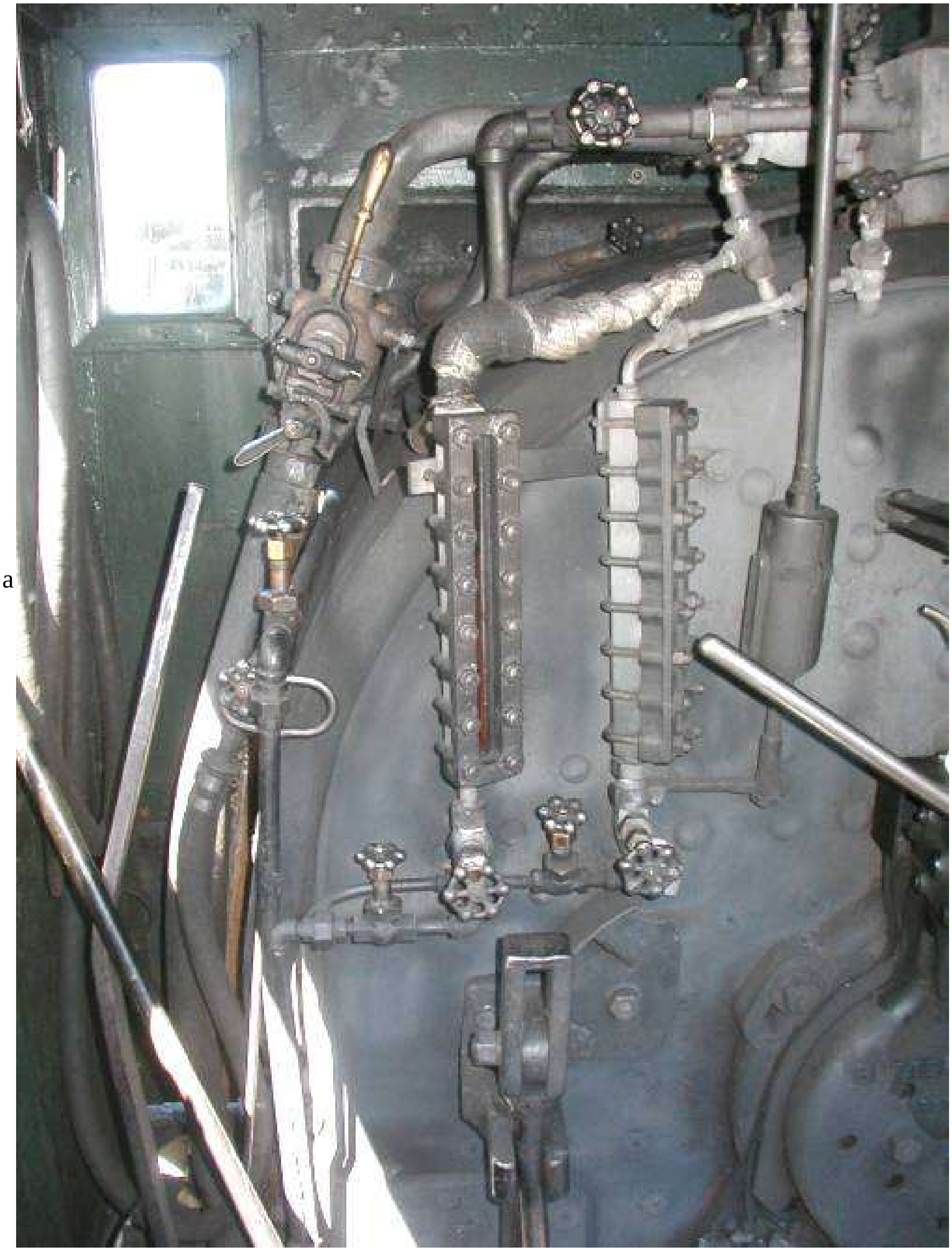


This shows the lower right side with a good view of the reversing lever. Several different types of oil cans are required plus a pretty good supply can. Also note that the interior of the cab is painted green.

This is the steam manifold on the top of the boiler. A good view of the boiler end of the throttle and the top of the two water gauges on the left.



This is the left side of the boiler with a good view of the dual water gauges. I think that's the injector just to the left of the boiler.



O-Rings: (Update 8/2003) I was getting ready to order some O-rings for the steam brake cylinder and ran across the following table from McMaster-Carr website and though others might find it useful. I'm using EPDM for the brake cylinder.

General Properties of O-Ring Materials (From McMaster-Carr Website)							
Temperature ratings and chemical compatibilities shown below are for general comparisons. See specific O-rings for more exact specifications, including temperature ranges.							
	Polyurethane	**Neoprene**	**Buna-N**	**Viton**	**Teflon**	**Ethylene Propylene (EPDM)**	**Silicone**
Low Temp. Rating	Good	Good	Good	Good	Excellent	Good	Good
High Temp. Rating	Fair	Good	Good	Excellent	Excellent	Good	Excellent
Resistance To:							
Compression Set*	Good	Excellent	Good	Good	Fair	Good	Good
Tearing	Excellent	Good	Good	Good	Good	Fair	Poor
Abrasion	Excellent	Excellent	Excellent	Good	Poor	Good	Poor

Ozone	Excellent	Excellent	Poor	Excellent	Excellent	Excellent	Excellent
Weather	Excellent	Excellent	Poor	Excellent	Excellent	Excellent	Excellent
Cold Water	Poor	Fair	Excellent	Fair	Excellent	Excellent	Good
Hot Water	Poor	Fair	Good	Poor	Excellent	Excellent	Good
Steam	Poor	Fair	Poor	Poor	Excellent	Good	Poor
Dilute Acids	Poor	Excellent	Good	Excellent	Excellent	Good	Good
Concentrated Acids	Poor	Excellent	Fair	Excellent	Excellent	Good	Fair
Dilute Alkalies	Poor	Excellent	Good	Excellent	Excellent	Excellent	Excellent
Concentrated Alkalies	Poor	Excellent	Good	Excellent	Excellent	Excellent	Excellent
Synthetic Lubricants (silicone grease and oil)	Poor	Poor	Good	Excellent	Excellent	Good	Not Recomm'd
High Aniline Lubricants (ASTM oil #1 or MIL-L-6082)	Excellent	Excellent	Excellent	Excellent	Excellent	Not Recomm'd	Good
Low Aniline Lubricants (ASTM oil #3 or MIL-H-5606)	Good	Good	Excellent	Excellent	Excellent	Not Recomm'd	Fair
Animal/Vegetable Oils	Excellent	Good	Good	Excellent	Excellent	Excellent	Excellent
Aliphatic Hydrocarbons (Fuel Oil A)	Good	Fair	Good	Excellent	Excellent	Not Recomm'd	Not Recomm'd
Aromatic Hydrocarbons (Fuel Oil C or Toluene)	Fair	Poor	Poor	Excellent	Excellent	Not Recomm'd	Not Recomm'd
* The amount an elastomeric material fails to return to its original size after release from a constant compressive load.							

Have I forgotten anything else? Probably. Will come back and update this as I progress.

Shay Home
NLW Home