Shay Operation - Improvements & Fixes

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Initial: 05/29/04 Last Revised: 06/03/2004

After the first run there were a number of items that needed improved or fixed. That will probably be the case for the first half dozen runs. This page describes these changes. The changes are also included on the pages that describe the construction of the specific part.

Blower: The biggest problem on the first run was that sufficient steam couldn't be generated on long grades. Also, there was some buildup of soot in the tubes. After the run the blower was checked by connecting compressed air to the boiler, opening the blower valve and observing the air flow out of the stack . There was very little air flow. The smoke box front was removed and the blower holes were examined. Several were blocked or restricted. This had happened before so there seemed to be a design problem.

Kenneth had specified four 1/32" (0.032") holes for the blower working with his propane burner. I recalled reading someplace that a good design for coal burners in six 1/16" holes. I think that was for larger locomotives than the 60 ton shay. I looked up Bob Reedy's design for his Three Truck Climax (July/August 2003 Live Steam) and found that he used four #55 drill (0.052") holes. Recall that I had copied Reedy's burner design so using the same size blower holes seemed appropriate. The exhaust nozzle was removed and the holes enlarged to 0.052".

What a difference! The expanded holes gives much more draft. With the less obstructive fuel filter installed a few weeks earlier, the burner has a much wider range of heat without smoking. The maximum heat output seemed to be maybe twice as much as before.

The blower is functional over a much wider range of blower pressures so the pressure gauge on the blower line was changed from 30 psi full scale to 60 psi full scale.

A second run at the track confirmed that this change to the blower fixed the steaming problem.

Tube Brush: The tubes had a soot build up so I asked Dave Johnson what he used to clean his tubes. He suggested a shotgun bore brush (Wal-Mart) connected to a long rod.

The photo on right shows a phosphor bronze wire bore brush for a 20 gauge shotgun that is a good match for the 1/2" copper tubes in the boiler. The photo below shows the finished tube brush

The end of the brush is threaded close to 5/16-24 --- maybe a metric thread. A 5/16-24 die was run over the thread to make it exactly 5/16-24. The rod is 1/8" diameter steel -- it must be flexible enough to bend around the exhaust nozzle to get to the lower tubes. A piece of 3/8" brass rod was drilled 1/8" on one end and drilled & tapped 5/16-24 on the other end. The rod was then silver soldered to the end of the 1/8" rod. The handle is 1/4" brass that is also silver soldered to the rod.

The photo on right shows using the brush. In this case the exhaust nozzle had been removed to enlarge the blower holes. All the tubes can be brushed with the nozzle in place. After brushing, soot was collected with the shop vac and then the shay was pulled out on the driveway away from everything and the tubes blown out with compressed air. The soot was swept up again and then the shay was given a bath.

Cleaning the tubes a couple times is an inducement to run the fire lean --- no smoke.

Lubricator: There were several problems with the lubricator:

- 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.

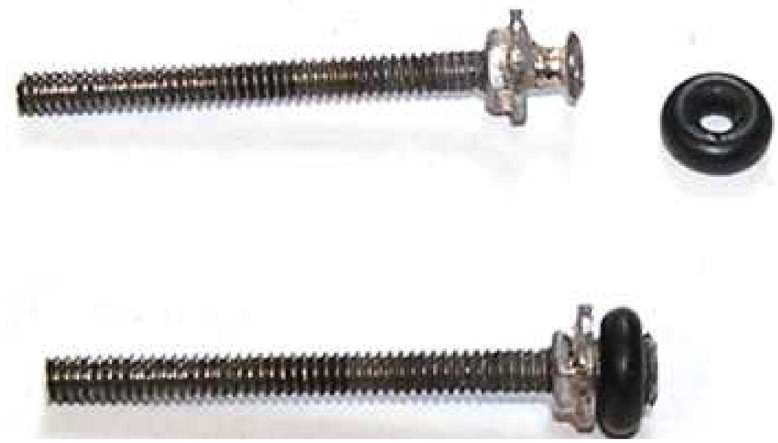
One concern with using a 1/8" tube compression to 1/8" NPT elbow at the stream header was that the 1/8" pipe size would seem way out of scale on the little shay. I found a 1/8" tube compression to 1/16" NPT elbow at McMaster-Carr --- part # 5053K57. This fitting is sold as "quick assembly" and comes 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.

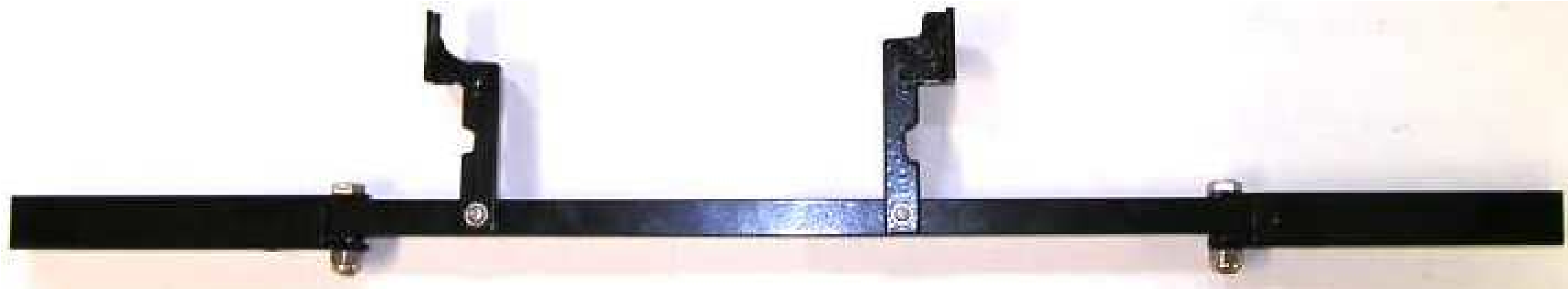
I've had about 8 hours operation with these poppet valves and no more trouble.

Steam Powered Water Pump: The pump started to run really slow. A few drops of silicone brake fluid in the steam line speeded it up for a few minutes but then it slowed down again. A lubricator seemed like a real pain. The pump was disassembled and the steam piston was found to be hard to push. A little water made it easier to push but still pretty tight. The depth of the gland was according to specifications --- but that was for a tight seal. For this application a slight leak is tolerable so the gland depth was increased to 0.100" --- a loose seal for the 0.103" O-Ring cross section. That seemed to fix the problem. After this fix I also had problems with the pilot valve rod and the connection between the shuttle valve pistons working loose. I finally bit the bullet and took apart each joint and applied high temperature Loctite (620) . The Loctite seems to have fixed that problem.

Brakes: The brakes seemed very slow to operate on the first run at the track. The valve was also leaking. Turns out that the O-Ring on the input steam line was cut, torn & pulverized. That explains the leak and loss of pressure. A new O-Ring was installed and the brakes then responded very quickly. The pressure on the O-Ring may have been too great so the screws attaching the cover were left a little loose which also made the valve operate smoother. The valve is functional but not up to expectations so a redesign on the list.

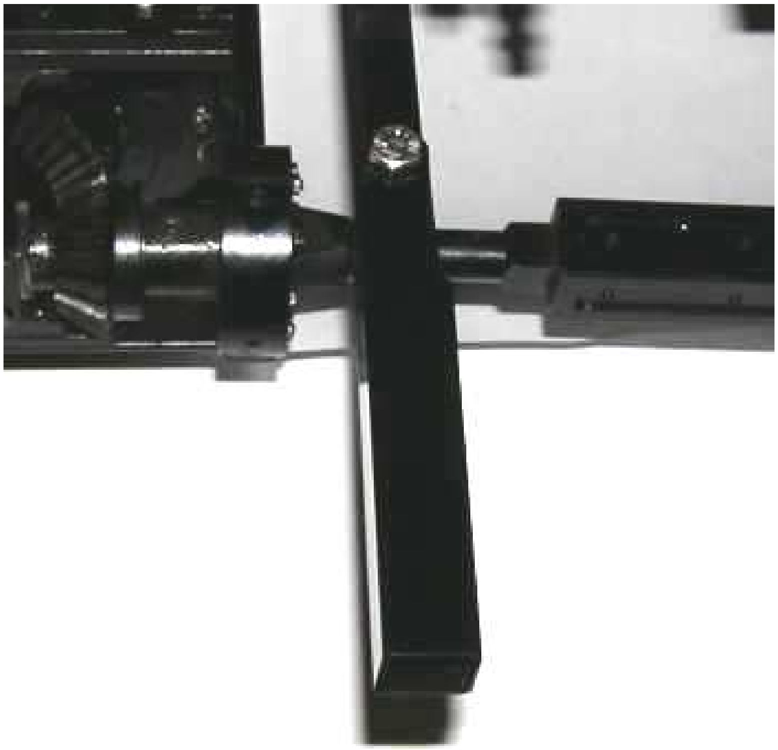
Footboards: The footboards below the front and rear sills were raised a half inch to avoid catching on things along the track.

Foot Pegs: A temporary set of foot pegs had been installed to test the peg position The pegs were fastened to the lower angles on the middle truck and were positioned about 2 inches in front of the middle truck and about 1" above the rail head. The position was good but so low that it was likely that they would hit things along the track such as switches. I didn't particularly like fasting the pegs to the truck either.

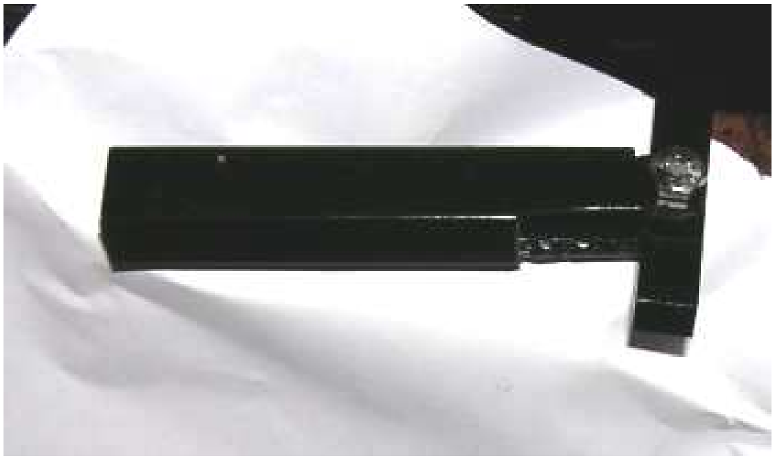


The photo above shows the final design of the foot peg unit. The rod is 1/2" square steel. The pegs are 1/16" wall 3/4" square tube obtained from the local hardware store. The bolts holding the pegs to the rod are 1/4" stainless with Nyloc nuts. A 1/8" thick shim was tack welded inside each tube to make up the difference between the the 5/8" tube inside dimension and the 1/2" rod. The hangers were made of 1/2" angle and attached to the rod with 10-32 screws. The hangers attach to the inside of the frame a couple inches ahead of the middle truck. The top of the hangers were shaped to get around other stuff on the inside of the frame. The left hanger is fitted around the low pressure return water line from the axel pump return valve (this line also feeds the steam powered pump). The cutout top of the right hanger is to provide clearance for the two water hoses connecting to the axel pump. The notches in the side of the hangers just above the rod are for the inside trust rods

This photo is an attempt to show the left side hanger. The tee is for the low pressure water --- the rear side of the tee goes to the tender, the center to the axel pump and the front side to the axel pump return valve and the steam powered pump input. The hanger is positioned just to the rear of the hanger for the tee. Two 6-32 screws through the frame into the hanger hold the hanger to the frame. The hanger was shaped such that the compression nut on the rear side of the tee could be removed. The hanger design would have been simpler if done first and then the plumbing designed to fit around the hanger.



This shows the right side foot peg. The bottom of the rod is just above the top of the universal ring.

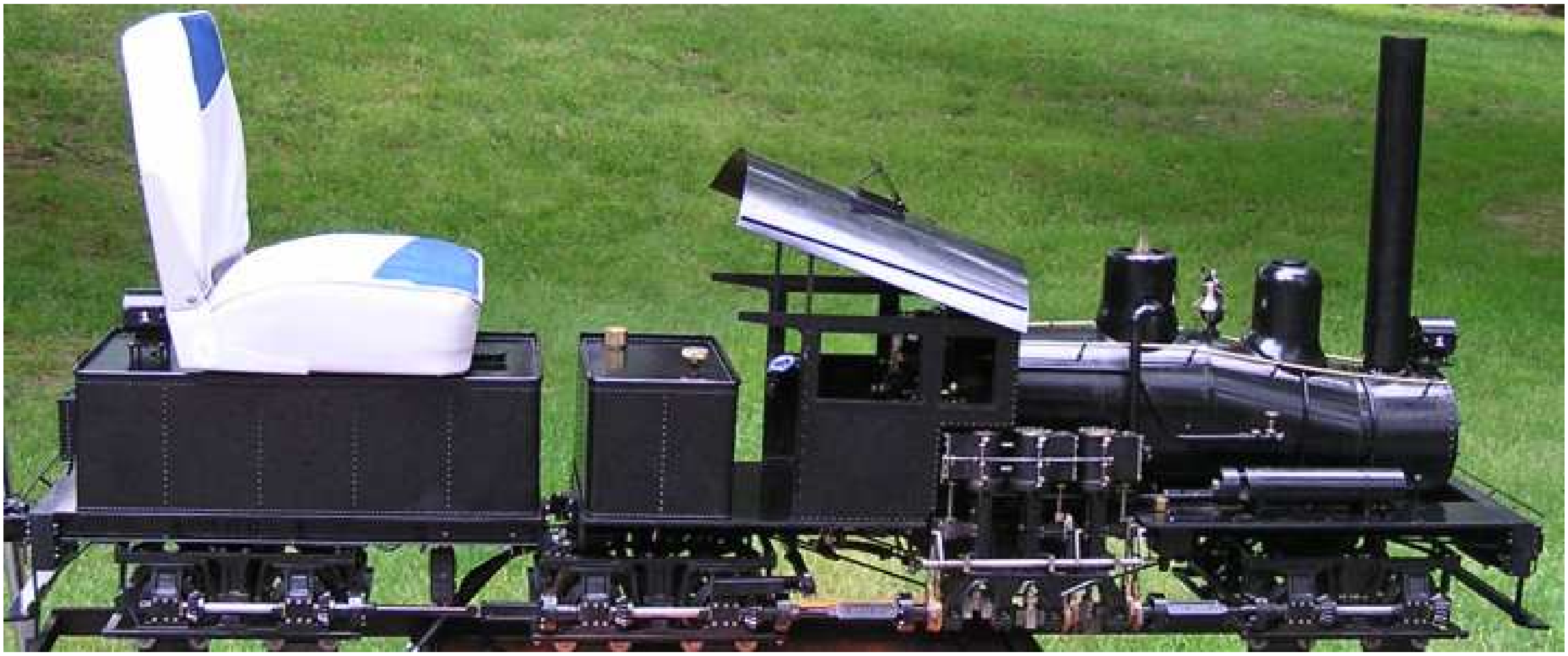


This the the right peg again with white paper under it so that it can be distinguished from the black truck underneath. The front side of the tubes were cut out to allow the pegs to fold back for transport. This also permits the pegs to fold if they hit something also side the track --- if the locomotive is moving in the forward direction.

Smokestack Extension: The 6" smokestack height is such that the smoke is head high when it reaches the engineer. An exhaust pipe extension was slipped over the stack to increase the height 12". That eliminated most the "smoke-in-the-eye" problem.

The extension in 18" long. The smaller end is approximately 2 7/16" OD, 2 5/16" ID and the larger end is approximately 2 5/8" OD and 2 1/2" ID. The larger end was squeezed in a vise to square it some so that it would fit over the square bottom of the smokestack and partway down the smokestack base. The part is Auto Works # 17625 and labeled 2 1/2" ID. The label also says made in USA. "Made in Canada" is stamped in the steel. Guess my geography is out of date.

Seat: Dick McCloy lent me a bass boat seat from Wal-Mart to try out for size. It seemed to work pretty well so I bought my very own. The selection of colors were gray with blue trim and gray with blue trim. A piece of old carpet was cut to the width of the tank top and one end screwed to the bottom of the seat. The carpet was then folded to make a double thickness and to protect the tender top from the screw heads. The seat just sets on the tender. The sides of the tender that stick above the tender top retain the carpet (and seat) from moving side to side. The seat can slide several inches front to back, limited by the lamp at the rear and the carpet running into the filler hatch in the front. The front part of the seat is over the filler hatch so the seat must be tilted back to add water or use the hand pump. The next photo shows the shay ready for use with engineer's seat, smokestack extension and cab roof raised. The cup holder and rear view mirror have been deferred.



Speedometer: One of the problems I had running the shay was to judge the correct speed. The shays were capable of pulling a relatively heavy load for their size but traveled very slow, typically less than 10 mph. Several of the guys suggested that I install a bicycle speedometer to measure both speed and distance.

So, off to Wal-Mart to get a speedometer.

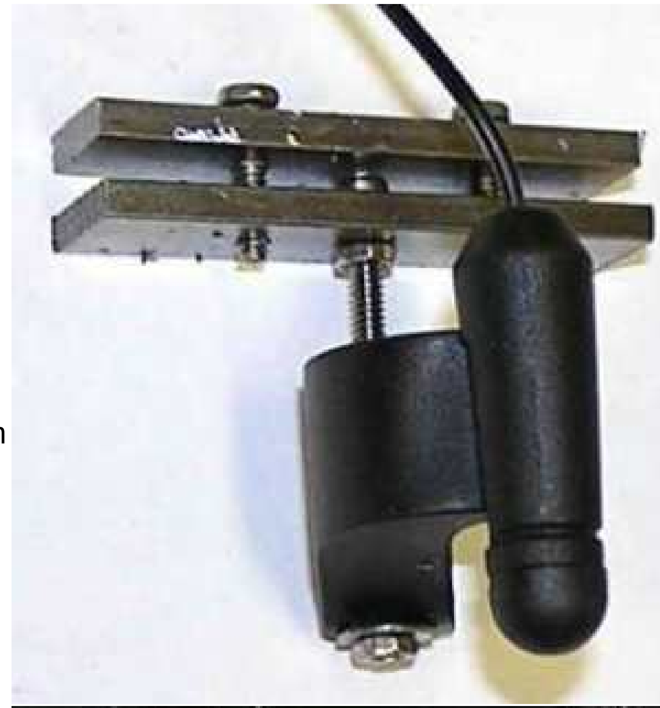
The unit has three main pieces, a magnet, a sensor and computer unit. The magnet is designed to clamp to a spoke on the bicycle wheel. The spokes on the shay wheels are too large so I cobbled up the adaptor on the right. That's a hose clamp, 4-40 screw, the magnet attached and a piece of 3/4" steel rod simulating a shay axel. The hose clamp is much larger than required -- it was all I had (late night project).

The side view of the magnet. The 4-40 screw with Nyloc nut was tightened to a hole in the hose clamp band. Loctite was used on the screw and in the magnet mount to hold it secure. The clamp was fastened to the rear axel of the middle truck next to the right wheel with the magnet pointing in.

Note that a concern was to keep the magnet fairly close to the axel so that it wouldn't be damaged if (when) the shay derails.

This is the sensor unit which is normally tired to the bicycle fork by a couple cable ties. The sensor is adjusted so that the face of the magnet passes within 3/16" of the domed end of the sensor.

The two 1/8" X 1/2" bars in the photo form a clamp to attach the sensor to the truck braces.   A hole was drilled through the sensor base for the long 4-40 screw that attaches the sensor to the bottom bar of the clamp.



This shows the the top of sensor with the clamp tightened to the braces. The clamp made it easy to adjust the business end of the sensor within 3/16" of the magnet.

The computer unit was mounted to a bracket that attached under the bottom two screws that hold the left side roof prop retainer to the side of the cab.

The computer unit is programmed to the specific wheel diameter (in mm). For the 32" shay wheel this comes to 2553 mm.   The display has many functions including calories burned (when riding the bicycle), time, elapsed time, clock, etc, etc. I set it for speed on the top (mph) and distance (miles) on the bottom in miles and hope I don't push the wrong button because I'm sure to misplace the instruction in a day or so.

Note that the unit reads scale speed and scale distance; in this case 10.8 mph and it has traveled 1.9 scale miles on the test stand.

A bit of black paint should make the speedometer match the cab decor.

Drying the Engineer: The engine exhaust has a low point directly under the smokestack. During the warm up period, steam that leaks past the throttle valve heats the cylinders and headers (good) and condenses in the exhaust pipe (bad). If the steam powered pump is used during this period, additional water collects. When the throttle is opened initially, the oil laced water shoots out the smoke stack and lands on the engineer. and everything else within a 6 foot radius. Once the engine is hot, most the steam and oil passes over the engineer and lands on any passengers --- a good design.

So, the biggest problem is the water collected during warm up. I drilled a 3/32" hole in the bottom of the exhaust pipe directly under the stack to drain this condensate. If I'd thought to drill the hole when I had the exhaust nozzle out to enlarge the blower holes, it would have been a small task. However, it was too late for that. I then remembered some long aircraft bits purchased years ago from a surplus store. . The smallest was 3/32" which set the hole size. Pulled the smokestack and ran the drill down the smokestack hole, through the exhaust nozzle and drilled the hole through the bottom of the exhaust pipe elbow.

The hole really worked. During warm up there was a steady dribble of oily water out of the hole. Once it was hot, the hole continued to drip with a significant oil content.

The hole probably causes some loss of draft, but not so much that it was noticeable.

Valve Timing: The shay ran much better at the second test run at the track. Enlarging the blower holes seemed to have fixed the problem with generating steam. The next area to look at was the valve adjustment to see if the engine was running at good efficiency. I had suspected the timing needed some attention but decided to try out the blower fix and then work on the timing so as to get a separate ,measure of each modification.

The engine must be removed to get at the timing adjustments. It takes less than 5 minutes to disconnect the reverse link, the flanges at the input and exhaust headers and the 4 screws holding the mount to the frame.

The front cylinder must be removed to get at the middle cylinder steam chest cover. That front cylinder was removed and then the timing of both the middle and rear cylinders examined. The timing was off quite a bit. It was probably not set accurately during the reassembly after painting. Most the eccentric straps were loose which introduced slack and delay. The straps were very tight when first installed --- so tight that they were run with loose screws for a while. (The engine has had at least 100 hours of operation on the test stand so the wear is due to that more than the half dozen hours at the track.) The straps were made tight again by filing a very small amount off the surface between the two halves of the straps. The timing was then set so that the amount of opening (lead) was the same at top and bottom dead center in both forward and reverse. Ken suggests that the valve should start to open at about 10 degrees before top/bottom dead center. I found that it didn't start to open till about top dead center --- about 10 degrees later.

The valve chapter in Joseph Nelson's So You Want to Build a Live Steam Locomotive seemed really boring before but now was very interesting and useful. The fact that the valves weren't open at dead center meant that there was essentially no lead. Lead is useful since it provides some compensation for wear. Joseph suggests a 1/32" lead (valve open 1/32" at dead center).

The engine was the first part constructed and it's likely that the dimensions are not exact. One good point is that the valves on the middle and rear cylinder seemed to have essentially no lead when the valve was adjusted so that it was balanced top and bottom and forward and reverse. Also, the position in these four states were very close. To get a little more lead it seemed that the the eccentrics should be advanced. I probably should have made a set of those valve diagrams described by Joseph Nelson. Instead I looked up Kozo Hiraoka's eccentrics in Building the Shay . Hiraoka has his eccentrics peak 109 degrees ahead of the crank peak (that is 19 degrees above the horizontal when the crank is at the bottom center). Kenneth has the eccentric peaking 100 degrees ahead of the crank (10 degrees above the horizontal when the crank is at bottom center). I decided to try a 105 degree advance (15 degrees above horizontal) on one of the cylinders. That gave some lead in all four states (top & bottom dead center in forward & reverse). The valve doesn't open in all states 10 degrees ahead of dead center as suggested by Kenneth ---- maybe an average of 5 degrees ahead of center. I failed to measure the lead but suspect it averages less than the 1/32" suggested by Joseph Nelson. The other two cylinders were also adjusted the same way with similar results.

So ----- what kind of a difference will these timing changes make? I had a week or so to think about it before I made it to the track.   It seemed to have more power on the test stand. One test I made was to determine the throttle setting at which I couldn't stop the engine with my two hands grasping the shafts. This seemed to be a significantly lower setting than before. The conclusion was much more power --- 50% more and possibly twice the power.

The test run confirmed that it is much more efficient ----- 50% to 100 % more so. The shay was able to pull two cars, one loaded with logs and another with one person up a ~ 100 yard long 3% grade at >20 mph (scale) and keep pressure such that the safety relief was open the whole whole time.

The shay is essentially complete and exceeds expectations. More tests with greater loads will be done over the summer and no doubt more improvements will be made.   Engineer experience will likely bring the greatest improvements. .

Shay Project
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