Shay - Engine Modifications

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The time had come to paint the engine. Since the engine had to be completely taken apart for the painting, I decided to try to fix two minor mechanical problems ----- leaking glands around the piston rods and valve stems seals and loose rod bearings.

Gland Seals: I had used threads of graphited yarn (from Coles) to pack the glands. With 6 glands on the engine, 1 or 2 always seemed to be leaking a little. My guess is that this is normal but with the shay engine standing up for all to see, it was clearly more noticeable than on the typical rod engine. I had made a Teflon seal for the gland on the throttle shaft and it worked pretty well. The EPDM O-rings used to seal the steam powdered water pump worked great also. The EPDM works pretty well on steam but doesn't tolerate oil --- and steam cylinder oil is added to the steam going to the engine. Went to the McMaster-Carr website and looked at their O-rings again. A table from that website is pasted below (they shouldn't object since I've recommended them as the source for many items used in the shay construction). Some of the O-rings types that were of no interest were eliminated from the table.

General Properties of O-Ring Materials (from www.McMaster.com)

Temperature ratings and chemical compatibilities shown below are for general comparisons. See specific O-rings for exact specifications. NR=Not recommended.

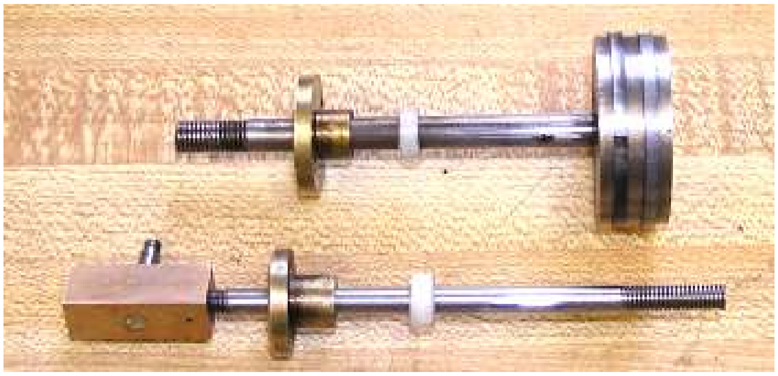
	Buna-N	Viton	Silicone	EPDM	Neoprene	PTFE	Kalrez®
Approx. Low Temp. Rating	-30°F	-10°F	-65°F	-40°F	-40°F	-100°F	-15°F
Approx. High Temp. Rating	+230°F	+400°F	+400°F	+212°F	+212°F	+450°F	+600°F
Resistance to:							
Compression Set*	Fair	Good	Good	Good	Good	Fair	Good
Tearing	Fair	Fair	Poor	Fair	Fair	Excellent	Excellent
Abrasion	Good	Good	Poor	Good	Good	Excellent	Good
Ozone	NR	Excellent	Excellent	Excellent	Fair	Excellent	Excellent
Weather	NR	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Water	Poor	Poor	Fair	Good	Good	Excellent	Excellent
Steam	NR	NR	Poor	Good	Fair	Excellent	Poor
Acids	NR	Good	Poor	Poor	Poor	Excellent	Excellent
Alkalies	NR	NR	Poor	Poor	Poor	Excellent	Excellent
Synthetic Lubricants	Good	Excellent	NR	NR	Poor	Excellent	Excellent
Animal/Vegetable Oils	Good	Excellent	Poor	Fair	Good	Excellent	Excellent
Anilines	Good	Excellent	NR	NR	Fair	Excellent	Excellent
Hydrocarbons	NR	Good	NR	NR	Poor	Excellent	Excellent
Detergents	Good	NR	Excellent	Excellent	Poor	Excellent	Excellent
Salt Water	Fair	Fair	Excellent	Excellent	Good	Excellent	Excellent
Hydraulic Fluid	Good	Excellent	NR	NR	NR	Excellent	Excellent
Alcohol	NR	NR	Fair	Fair	Good	Excellent	Excellent
Refrigerants	NR	NR	NR	NR	Good	Excellent	NR
Ketones	NR	NR	NR	Poor	NR	Excellent	Excellent

* Refers to a material's ability to return to its original size after it's been compressed.

PTFE is the clear choice from the table. The weakest point is the compression set. Other literature indicates that PTFE seals work very well in a confined space --- such as a gland. Now what is PTFE? An Internet search revealed that PTFE is the abbreviation for Polytetrafloeraethylene, more commonly known by the trade name "Teflon". Hmmm --- seems I've come full circle here. After learning this I went back to some of the data on O-rings I put in one of the pages about plumbing and found a table similar to that above also taken from the McMaster Carr website but a year earlier. On that table Teflon O-rings were listed. Apparently McMaster-Carr switched from the term Teflon to PTFE between 2003 and 2004.

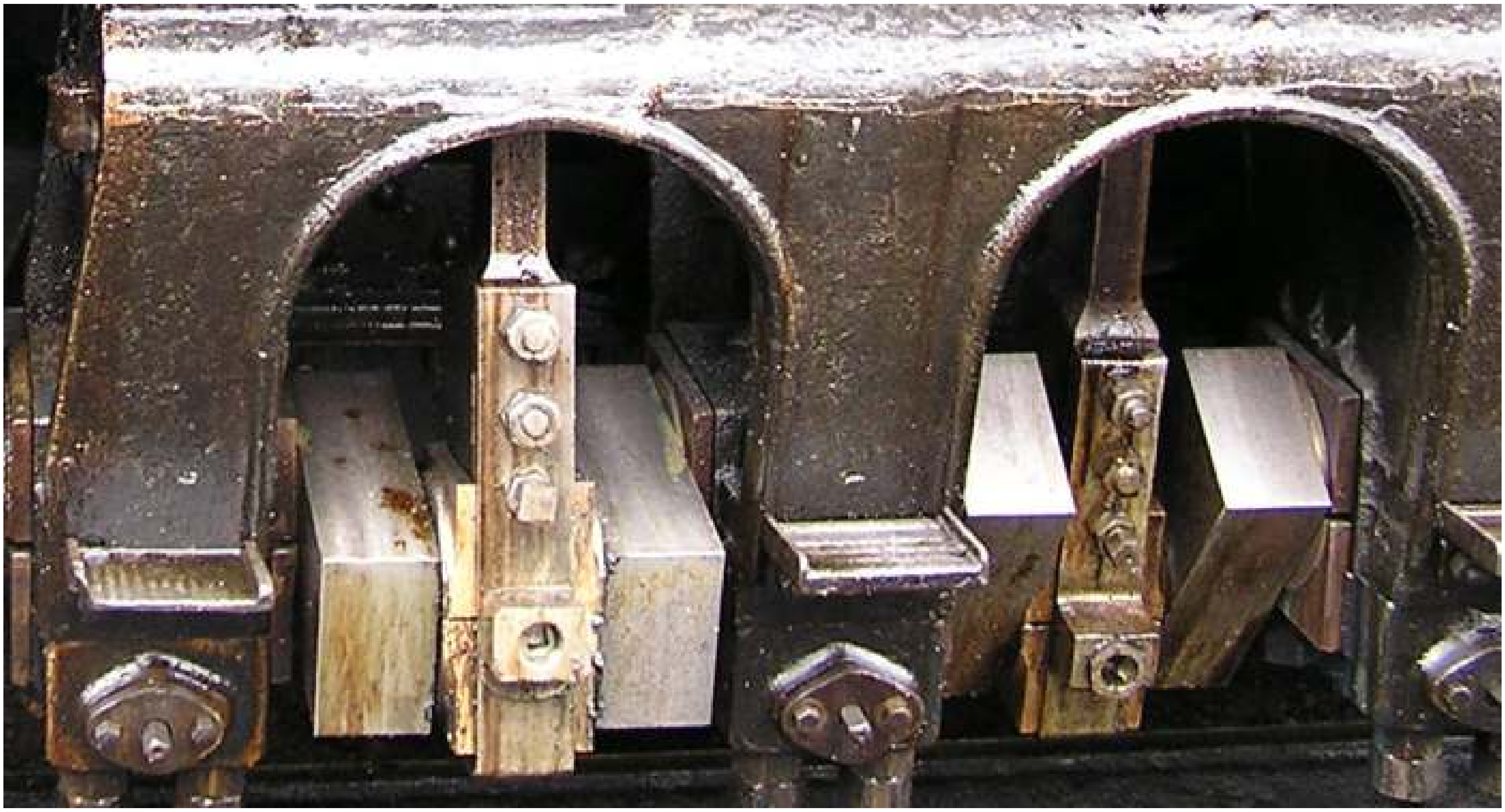
Master-Carr sells a bag of fifty 3/8" OD PTFE O-rings for ~ $12 plus tax and shipping ---- and two different IDs are required --- that's up to about $30. Found a short piece of 3/8" OD Teflon rod left over from the cylinder cocks so decided to make my own O-rings.

Teflon Seals: Since the seals were fabricated from a rod I purchased under the Teflon name they are Teflon, not PTFE seals. For this application a rectangular cross section seemed appropriate and 1/8" thickness looked good (translation ---- a 1/8" thick 3/8" OD flat washer with 1/4" ID for the cylinder rod and 3/16" ID for the valve stem). The photo shows the finished seals.

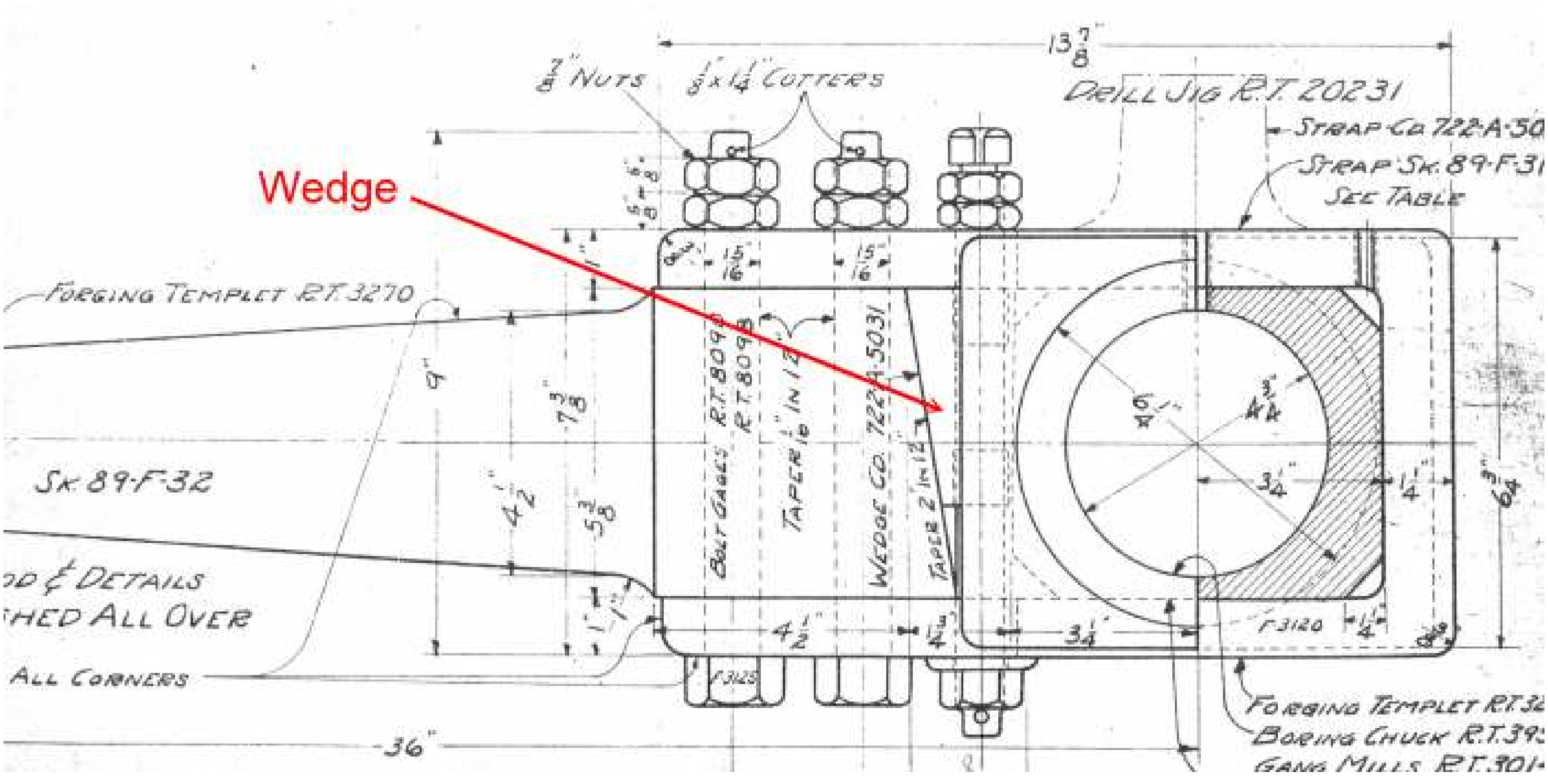


Before leaving the subject of PTFE or Teflon I wanted to point out that an unconfined Teflon washer doesn't make a very good seal for steam. I tried Teflon washers between the drain cock and the bottom of the water gauge and also on the input and output of the atomizer regulator. These joints use straight rather than tapered threads. All leaked when heated and attempts to increase the pressure on the Teflon washer merely caused it to squeeze out the sides. The Teflon washers were replaced with aluminum washers which sealed properly.

Rod Bearings: The connecting rod bearing is held to the end of the connecting rod with a simple U shaped strap. The strap is secured to the rod with three bolts. The problem is that there is no force to hold the two halves of the bearing together. The bearings and straps were clamped to the connecting rods as tight as possible before the holes were drilled through the straps and rods but all the bearings were slightly loose. In one case the bearing was loose enough that there was a slight knock.

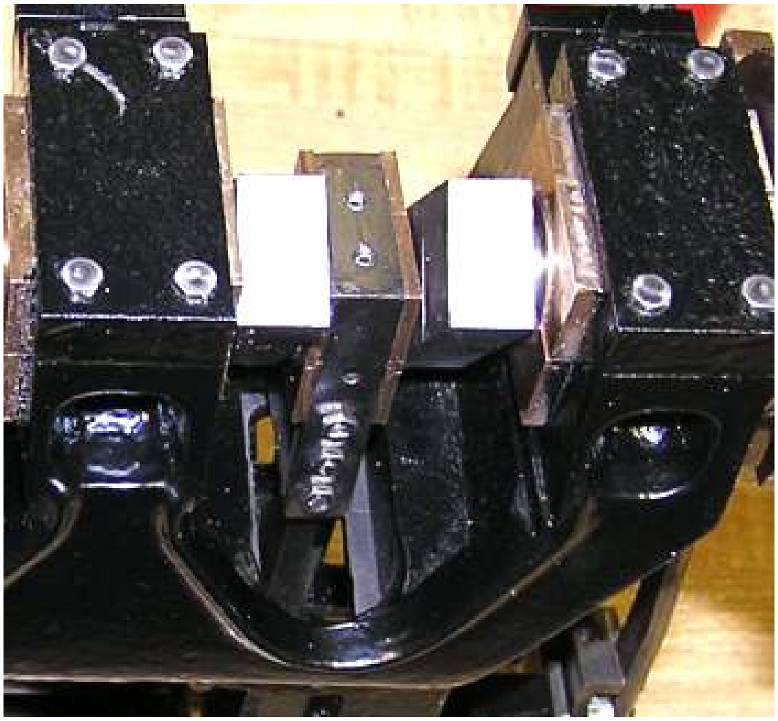


The photo above is of the engine on Cass 11. The square thing on the strap adjacent to the split in the bearing halves I assume is an oilier. The bearing straps have three bolts retaining them to the connecting rods. However, close inspection reveals that the lower of the three bolts is a little different than the other two. Also, the lower bolts on the two rods shown are different, the one on the left has a square head and the one on the right has a hex head. (I assume some purest would model this exactly and then would be all shook up on a subsequent visit to Cass where he found the those bolts reversed after an engine overhaul.)



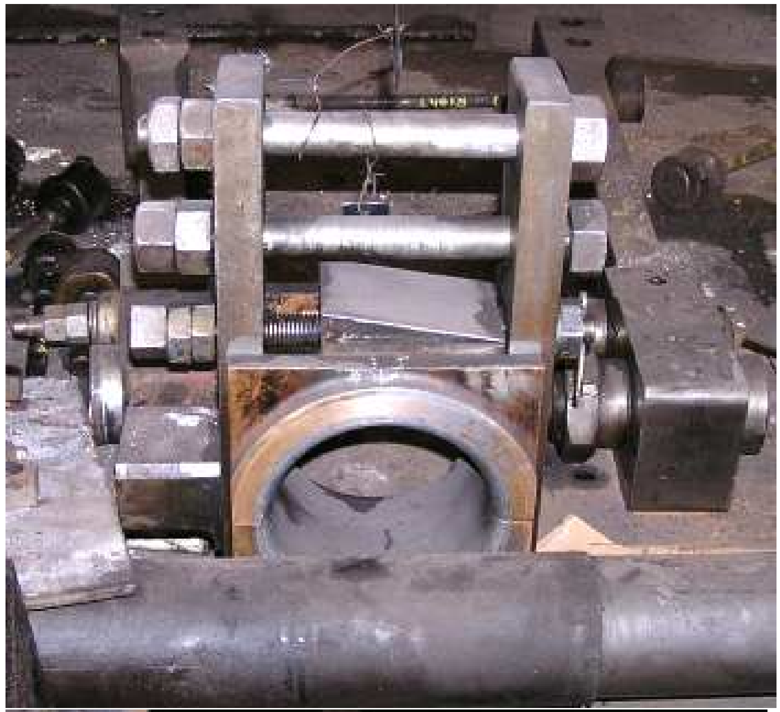
The image above was scanned from a section of the a Lima drawing for a connecting rod. Note that there is a wedge between the bottom end of the connecting rod and the top bearing half. The bottom end of the rod is also wedge shaped. The lower bolt is threaded the entire length and does double duty. Turning the bolt moves the wedge against both the bottom of the rod and the top bearing half. The double hex nuts secure the lower bolt after the adjustment. (If one were an overachiever when tightening the wedge and twisted the end off the adjusting bolt, disassembly could be avoided by welding a large square nut on the end of the bolt.)

Modified Strap: It seemed like too much work to incorporate the wedge into the design, especially since the straps and rods were completed. Instead, a couple 1/8" long 4-40 setscrews were put in the bottom of each strap as shown in the photo. This seemed to work great in that the bearings are now tight. There is a possibility that the setscrews will work into the bearing and the whole thing becomes loose again. If that happens, 1/16" can be milled off the bottom of the bearing and a 1/16" thick steel shim can be inserted between the bearing and the bottom of the bearing and the strap. The setscrews can then be tightened against the steel shim.



Update3/25/2004: Made a trip to Cass this week to take a few measurements and photos. This photo shows the disassembled engine for one of the later shays.

Wedges: This is one of the rod bearings & straps for the engine in the above photo. The wedge described earlier is clearly visible.



This shows the wedge-shaped end of a connecting rod on one of the shays outside the Cass Shops. It should now be clear how the wedge forces the two halves of the rod bearing together.

Valve Timing: On the first test run there was a problem with the blower holes plugging up. The shay ran much better at the second test run at the track after the blower holes were enlarged. 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.

Shay Project
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