Crosshead Pump Efficiency

I had been puzzled by the performance of the crosshead pump on my Maxitrak loco for some time and more so recently as I had become convinced it wasn't up to the task. So I decided to do some tests to see how fast the loco consumed water and how fast the crosshead pump replenished the boiler. I performed the tests on a rolling road so there were no loads or gradients to work against, which I knew would stack the results in favour of the pump. I then complicated the experiment by renewing the pump ram o-ring and modifying the pump inlet chamber at the same time half way through the tests.

The Experiment

I put two stickers on the water gauge, one about a quarter the way from the bottom and the other about a quarter the way from the top. The gap between them represented 300ml of boiler water. So now, for a given speed, I could measure a) the time taken for the loco to get through 300ml of water with the crosshead pump bypassed into the side tank and b) the time taken to replenish the 300ml of water in the boiler using the crosshead pump, along with the total amount of water consumed over that period (by measuring the amount of water needed to refill the side tank to a known starting point).

Fig 1. Cab view of loco showing markers on the water gauge

The Results

I ran a number of tests and the first thing I noticed was that the loco consistently used 0.15ml of water per wheel revolution (per rev, from now on), no matter what the speed

when the crosshead pump was diverted (i.e. not filling the boiler). That might have been predictable if the steam pressure had been the same throughout all the tests but it varied from about 50psi to 80psi. It is likely my tests weren't accurate enough to pick up any variations due to steam pressure.

The first batch of boiler filling tests were using a worn o-ring and the standard pump and the results can be seen in table 1. Clearly the faster the loco the more inefficient the pump. At 2.1mph it would take 1.6 laps of Puffing Field to put 300ml water in the boiler. Bear in mind that under track conditions, the water consumption is likely to be appreciably more than the 0.15ml per rev so I might be looking at two or more laps needed to replenish the 300ml. Clearly that isn't good enough considering that if I went faster the situation gets worse.

Worn O-ring and pre-modification			
Track Speed (mph)	Pump Efficiency	Time to Fill (mins)	Laps to Fill
2.1	57%	7.0	1.6
2.8	38%	5.8	1.8
4.7	23%	9.8	5.1

Table 1: First Batch of Tests

For the second batch of boiler filling tests I replaced the o-ring, which from experience does make a noticeable difference, and I modified the inlet chamber of the pump by creating more space for water to pass the ball bearing on its way to being drawn into the pump. The indentations in the bearing seat were imperceptible originally so I couldn't see any way 1ml of water could successfully be drawn in in the time it took for the ram to be drawn back. So I increased the size of the indentations with some delicate file work!

The results of the second batch of tests can be seen in table 2. The 100% pump efficiency at 3.1mph is probably a rounding error but its clearly close to that figure. Again the pump efficiency noticeably tails off as speed increases. At 3.1mph 300ml will be put into the boiler in 0.7 laps of Puffing Field but it would take a ridiculous 5.5 laps at 6.3mph.

New O-ring and modified			
Track Speed (mph)	Pump Efficiency	Time to Fill (mins)	Laps to Fill
3.1	100%	2.2	0.7
4.1	34%	6.0	2.7
6.3	30%	8.0	5.5

Table 2: Second Batch of Tests

Fig 2. The loco on the rolling road on an overcast day

What is going on?

My tests didn't reveal the water consumption under the load induced by using the pump to fill the boiler as I couldn't separate it out from any loss of water through use of the blower to keep the pressure up. In the first batch of tests the loco speed didn't drop much when I switched the pump to the boiler, which is a suspicious sign in itself. In the second batch there was a noticeable drop in speed as the engine worked the pump. This necessitated more regulator so its fair to assume more than 0.15ml was being used per rev when filling the boiler.

The tests were focused on replenishing the boiler but if I take a different perspective and assume I will be turning it on and off regularly to try to maintain a boiler water level then 1ml per rev from a pump should be fine even if the 0.15ml on a rolling road turns out to be

three times that at puffing Field. In that case I should have the pump on about half the time on average. Previously I had needed the pump on all the time and still needed to stop regularly to use the hand pump.

There remains the dramatic fall off in pump efficiency as speed increases in both sets of tests to explain. My belief is that as speed increases the pump fails to fill the barrel with water and instead fills it with a mix of water and vacuum. Its also possible some air bypasses the o-ring, which would be consistent with the odd drop of water that escapes from the pump as shown in figure 3 below. So it looks like the minimum time needed to fill the pump barrel is when the loco is travelling at about 3.1mph (could be a bit higher), which corresponds to 4.4 revs per second, which in turn is about 0.11 seconds for the ram out stroke.

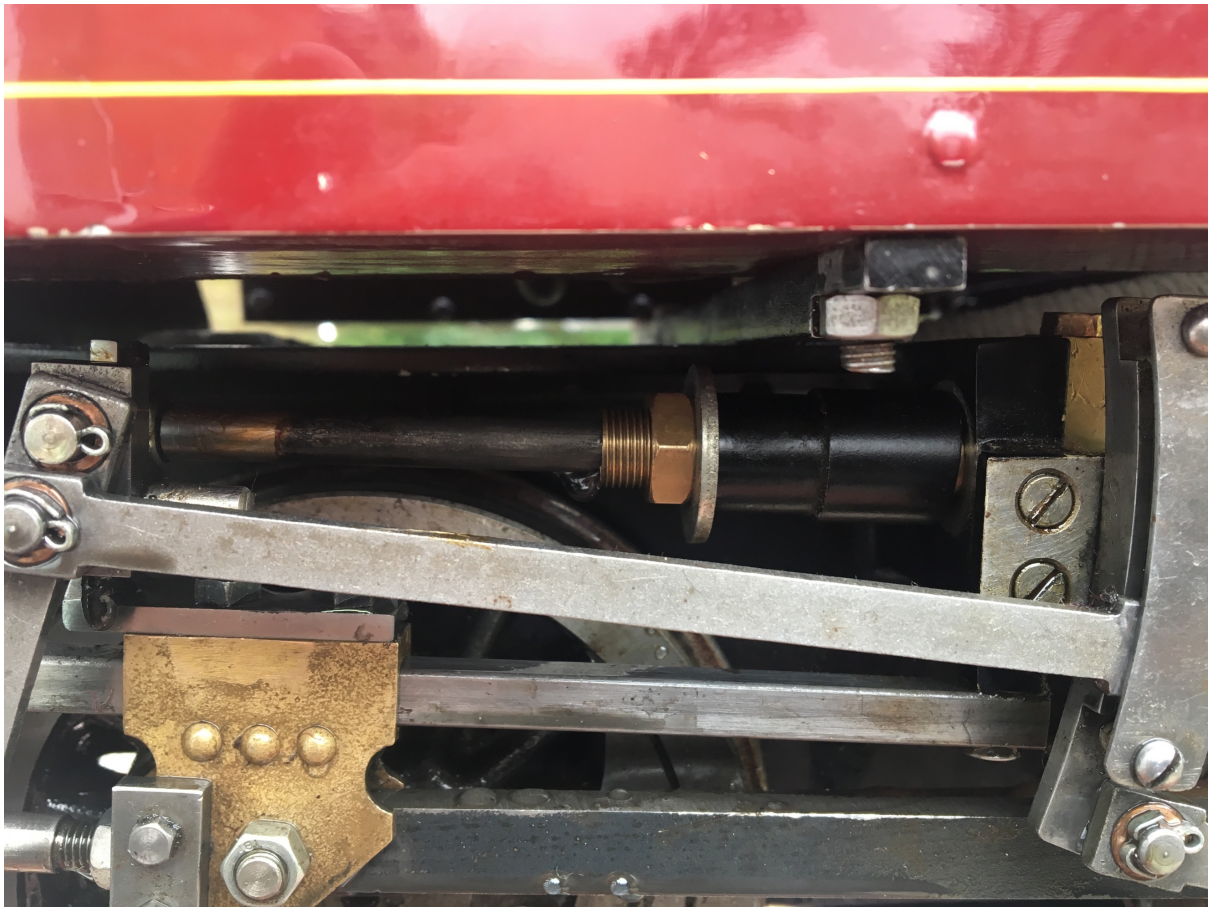

Fig 3. Crosshead pump

What Next?

My next step is to replicate these tests at Puffing Field to understand the effect of loads and gradients and to see if the pump is now good enough for general use. However in the mean time I need to fix the failed steam oil pump!