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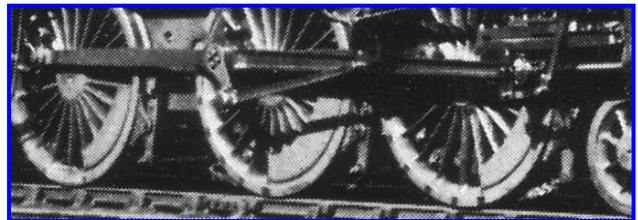
Locomotive wheel balance and Hammer Blow

This document was written by Mike Wheelwright and was originally published by Worthing and District SME in their newsletter in the Summer of 2009

Hammer Blow

I imagine that nearly all locomotive enthusiasts will have come across the expression “hammer blow” but I wonder how many of us really know what it is. It sounds as though the engine is hammering the track as it runs: in fact, this a pretty good description of what is happening, but what causes it? No, it is not the force of the coupling rods as they move up and down, in fact it is a force that the designer deliberately builds into his engine. This does not mean that engineers are mad (well not all of them) but it is the usual story of all engineering where perfect solutions do not exist and at the end of the day trade-offs have to be made to reach an acceptable compromise. Intrinsicly the Stephenson railway engine has two types of out-of-balance masses, rotating and reciprocating.

Coupling rods and crank pins are heavy parts that rotate: when they are horizontal, half way between their highest and lowest positions, they are moving quickly up or down. How quickly? On a LMS Class 5 running at 60mph the crank pin rotates at 23 mph. So, at one instant we have a heavy weight moving down at 23 mph and $\frac{1}{4}$ of a revolution later it has no vertical motion at all, i.e. it has stopped in $\frac{1}{20}$ second, and the force to stop it has come through contact with the rail: wallop! Naturally the opposite happens on the up-swing where the mass tries to lift the wheel off the rail. In the horizontal plane the same forces cause the whole locomotive to surge back and forth at each revolution. Of course, this must not be allowed to happen and fortunately there is a simple trick to prevent it: balance weights in the coupled wheels. By casting in extra masses on the circumference of the wheel centres, or by attaching plates in the same place, opposite out-of-balance mass is provided in each wheel set (pair of wheels and axle) to offset the rods. In the case of crank axles the rotational mass of webs, etc, has also to be allowed for and the balance weights are not exactly opposite the outside crankpin.



The reciprocating masses come from the piston, piston rod and crosshead as well as part of the connecting rod. At half-stroke this mass moves forwards at 23 mph (relative to the engine) then $\frac{1}{10}$ second later it moves backwards at the same speed, giving the driving axle boxes two great wallops five times a second. So, you say, “OK, why not stick bigger balance weights in the driving wheels to neutralise things?” Well, that’s more or less what is done, when they are moving forwards or backwards the extra balance weights compensate for the horizontal reciprocating force but there is a problem in the vertical plane as they are unopposed and wallop the track. The technical term for wallop is Hammer Blow. I told you the hammer blow was designed in! At one extreme without reciprocating balance the engine surges dangerously, at the other with 100% balancing it runs forwards smoothly but hammers the track and jumps up and down. As usual a decision is taken somewhere between the two and depending on the engineer about 50 to 70% of the reciprocating mass is balanced.

The size of the problem depends on the design of the locomotive, for instance those of you who have ridden in the first carriage behind a “Hall” will remember the surging, for like most GWR 2-cylinder engines they have a 30” stroke, so the out-of-balance effect is greater. Engines with more than 2 cylinders can be arranged to have no out-of-balance forces so no hammer blow is created. The GWR French atlantics did not sell the

benefits of compounding to Churchward but the smoothness of balance between adjacent cylinders working at 180° pretty quickly had him put the Swindon drawing office to work on a 4-cylinder 4-6-0 for fast express work.

The avoidance of hammer blow for GWR engines of lower order where axle load and speed were not critical was not considered worth the additional cost involved. Due to the inside and outside cylinders driving on different axles the GWR layout is not truly balanced as the opposing reciprocating forces are taken through the leading coupling rods, but the locomotive as a whole is in balance. Multi-cylinder engines driving on the same axle are fully balanced; this is the case for the 4-cylinder Claughton and the 3-cylinder locomotives of the NER, GNR and LNER. This latter railway evidently considered that the extra complication and cost was not only worth it for greyhounds (Gresley pacifics) but also for carthorses (O2 2-8-0), but nobody else took this view. As a final comment just consider our engines. We don't go in for balancing, we don't need to as although scaling effects are usually against us, in this case they work in our favour and forces are about 1/20,000 of full size. However, when building the Claughton I was surprised how significant the reciprocating effect was. At the stage of testing on air, as the inside valve movement is derived from the adjacent outside valve, I decided to dismantle the inside motion and start up just on the outside cylinders. When I ran the engine on blocks the usual rocking back-and-forth movement happened but after restoring the inside motion I ran the engine on 4 cylinders with absolutely no vibration at all. So, small they might be in 5" gauge, but reciprocating forces are noticeable.