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Compound locomotives in 5 inch gauge

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Over the years of building 5" G engines, I have established my own design principles for most features, some of which like boiler, draughting, cylinders and valve gear are important for good running and where small changes can have a significant effect. My most recent effort was a Midland Compound. The choice of prototype was strange as my youthful recall of them was not particularly favourable, but I was much impressed by an article in ME magazine showing the appearance of the original Johnson engines and the challenge of reproducing a working compound in our size became irresistible. This opened up quite a new world since it was not immediately obvious whether my well-established rules and practices could be applied directly to a compound engine, and I had to make a few difficult decisions not knowing how things would turn out. Now that I have got 5" G MR No.1004 sorted out I know a bit more about the "ins and outs" of a compound.

The model is a 4-4-0 with two outside cylinders $1\frac{5}{8}$ " D x $2\frac{1}{4}$ " stroke with slide valves and a single inside cylinder $1\frac{1}{2}$ " D x $2\frac{1}{4}$ " stroke with outside admission piston valve, each with its set of Stephenson Link Motion. The inside High Pressure (HP) cylinder is supplied with steam from the boiler at 90psi which then passes into a cavity in the block (the receiver) for further expansion in the two outside Low Pressure (LP) cylinders before leaving through the blast pipe as usual. The volume of the HP cylinder is 4.0 in^3 and that of each LP cylinder is 4.7 in^3 so the total HP to LP volume ratio is 1 to 2.35. Conventional engineering practice when dealing with compounds is to rate power on the basis of the boiler pressure and swept volume of just the LP cylinder. This ignores the HP cylinder but on reflection it seems right as steam that was originally supplied at boiler pressure is expanded until it occupies the volume of the LP cylinder; whether the expansion and extraction of energy happened in just this cylinder (simple expansion) or partly in another one is immaterial. This idea was useful in visualising the model as it gives a sort of parallel between the 3-cylinder model Compound and a simple engine with just two outside cylinders supplied directly with steam: in other words, a comparison between the model Compound and an outside cylinder "Maid of Kent".

The boiler did not need much thought. A few two-cylinder engines were built at Derby for trial purposes and they were given the same boiler as the Compounds so I did likewise. I modified LBSC's Maid boiler to increase the firebox to scale length and rearranged the tube layout to improve the free gas area. The next consideration was the size of the cylinders, the outside ones at 21" dia. would be $1\frac{7}{8}$ " posing a problem of excessive width due to the inevitable over-scale thicknesses. Experience from Maid of Kent tells us that $1\frac{5}{8}$ " cylinders are more than adequate to provide all the tractive effort that can be

handled without slip so this, together with the availability of suitable castings from another model, settled the outside cylinders.

The prototypical HP-LP volume ratio of 1 to 2.4 is about right for obtaining the same work from each stage of expansion so I decided to stick with it, and the nearest round figure for the diameter of the inside cylinder was $1\frac{1}{2}$ ". The valve gear for the LP cylinders is conventional, more or less what I would use for a 2-cylinder simple. The lap is 0.125" and the Stephenson gear is laid out with a maximum travel of just under $\frac{1}{2}$ " giving a steam opening of 0.120" and lead of 0.009" with cut-off at 74%: there is a reason for this rather limited cut-off. After the early experimental phase, the HP and LP cylinders of the Midland engines were linked-up together using a normal reverser, but indicator diagrams showed that the single HP cylinder was doing a good deal more than its fair share of work, almost half of it in fact.

Of course, this should have been no surprise as the volume ratio of 2.4 is selected to divide the work output equally between HP and LP expansions and each LP cylinder would therefore do about a quarter of the work, but for mechanical balance something like a third from each cylinder was preferred. The output of the HP cylinder was reduced by "fudging" the valve events so that the LP cylinders cut off about 10% earlier thereby increasing the pressure in the receiver. I wanted to do the same but was concerned that as the engine would

rely on the outside cylinders for starting there could be difficulties if the maximum cut-off was too short so a good old compromise of 6% less was chosen, hence the 74% maximum. The later HP cut-off was obtained by reducing the lap to 0.094", a maximum travel of $\frac{7}{16}$ " gives 80% cut-off and the lead and steam openings are similar to the LP side. In practice things work out reasonably well with 20 to 25 psi showing in the receiver when running hard in full gear, I would have liked more but even so this provides a contribution to tractive effort from the LP cylinders of about 13 lbf, which combined with the HP output (estimated at 10 lbf) approaches the adhesive limit of a 4-4-0. The engine can be notched-up a few turns but then power falls away rapidly, not surprising as of course all the steam has to pass through the single HP cylinder and the amount admitted is reduced when the valve cuts off earlier.

It is interesting to analyse how the compound engine works compared with an equivalent simple engine, Maid of Kent style. To see what happens we can use a bit of information taken from my valve events design sheets, and a few calculations reveal the difference between the two alternatives. The volume of steam taken in is the volume of the HP cylinder when the piston is at "cut-off", likewise the volume of expanded steam is the sum of both LP cylinders at the point of "release".

At 80% of stroke (cut-off) the HP volume available for live steam is 3.42 in³ and this steam eventually expands to fill the combined LP cylinders just before release at 92% stroke when it occupies 9.15 in³, so the overall expansion is 2.67 times. The figures for an engine using just the LP cylinders directly supplied with steam have to be based on an earlier cut-off so that the combined input volume is the same as the compound (3.42 in³), i.e the boiler is being worked equally hard. For this the cut-off must be shortened to 31%, the corresponding release then occurs at 73% with an expanded volume of just 7.37 in³, i.e. 2.14 times. As expected, the steam expands more in the compound so in theory it is more efficient. However, there is another difference of much greater significance; port

openings: the simple when linked-up only opens 0.040" against the 0.125" of the compound's HP port. This is not quite as bad as it looks as each outside cylinder only handles half the steam, nevertheless the simple cannot realistically be worked at this early cut-off due to insufficient admission of steam so it loses out. However ... if we built a simple engine with better cylinders and valves could it do as well as the compound? For the answer have a look at The Big World!



Finally, I really did not know what to do about the size of the blast nozzle. My usual "standard" is $\frac{1}{5}$ of cylinder diameter, however I stress that this only works in conjunction with a low resistance tube layout and optimum smokebox draughting. But in a compound, this would be based on how many cylinders, of which diameter? Would the soft exhaust pull enough vacuum? After reasoning along the lines of power output I risked a calculation using the two LP cylinders as the basis, so for $1\frac{5}{8}$ " D the nozzle was 0.325". I usually start out $\frac{1}{32}$ " smaller "just in case" and then open out if necessary. So, it proved with the Compound, I had to increase the blast pipe to the calculated diameter to keep the valves from blowing off, fancy that, no different from a simple. You live and learn, don't you?