# Piston vs. Caprotti Valves - The Final Discussion?

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The following discussion is a response by David Wardale dated 3rd Sept 2009 to several observations and comments put to him by John Duncan in support of the adoption of British Caprotti valve and valve gear on the 5AT locomotive.

Wardale's responses are published on this website at his request. He presents 28 responses, each being preceded by the individual comment to which it relates.

*Note: Both John Duncan's original comments and David Wardale's responses have been transcribed from image scans into digital format. Every effort has been made to ensure correct transcription.*

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**Note:** John Duncan's comments 1 to 7 (below) relate to a statement by Wardale that appears on this website, saying:

"Caprotti valve gear is expensive specialist equipment, so piston valves and Walschaerts valve gear have been chosen because with Porta refinements they give a performance of the same standard and at much lower capital cost. Indicator diagrams from the "Red Devil" - which the 5AT will greatly improve on - have proved that. Can Mr. Attewell produce figures to show that poppet valve gear requires "considerably less" power to drive than Porta-type lightweight piston valves driven by Walschaerts gear running in needle roller bearings?"

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**John Duncan's Comment 1**

> Cost:- In the 1957 build BR Std. '5' Walschaerts valve gear 73165-71 cost £25,606 per loco. In the 1957 build BR Std. '5' British Caprotti valve gear 73146-54 cost £28,469 per loco. Difference in capital cost of £2,863 per locomotive, a small amount of capital cost (10%) compared to the cost of mileage exams on a piston-valve fitted locomotive.

**Wardale's Response:** The BR5 increase in capital cost for Caprotti valves is 11.2% from the cost figures you give, not 10%. If this *were* replicated for an actual 5AT construction cost of, say, £3 million, it would amount to £336,000, not a "small amount." However it is not possible to say what the relative costs for the 5AT would be. In the case of the BR5, BR workshops were fully tooled up for producing piston valves and Walschaerts gear, whereas relative to this Caprotti gear was specialist (see point (3) below), and the engines so fitted had to have different cylinders, probably quite an additional expense. For the 5AT everything has to be designed and produced from scratch, the piston valves and Walschaerts gear are more sophisticated than in BR times, and *everything* associated with steam locomotives tends to be in the nature of specialist equipment now. Hence the relative cost is an open question. The only way to settle it would be to make 100% detailed designs for both and have them costed, not an exercise likely to be done.

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**John Duncan's Comment 2**

> The British Caprotti valve gear ran from General Overhaul to the next.

**Wardale's Response:** "British Caprotti valve gear ran from [one] general overhaul to the next." On average the BR5s on the LMR ran some 189,000 miles (302,000 km) between general overhauls from data given by Cox for 1957 (a figure, incidentally, easily beaten by the Southern West Countries which were then almost all unrebuilt - so much for commonly held perceptions!) From page 241 of *The Red Devil* you will see that the piston valves, rings, spindles and valve liners of that locomotive required attention only at 250,000 km intervals. Other things being equal, the distance travelled by a piston valve, and hence its wear, per km is inversely proportional to the coupled wheel diameter. Adjusting the above figure for the larger wheel size of a BR5 vs. the 26 Class (74" vs. 60") gives 308,000 km. Therefore we have already shown that Porta type piston valves would also go from one general overhaul to the next without attention. But this does not allow for the 26 Class figures being depressed because of incorrect materials being used for certain valve components, intermittent lubrication starvation, and a persistent foaming/priming problem, the scourge of lubrication. All this is documented on page 240 of *The Red Devil.* Without these, the periods between attention would be longer still. The same period - or longer - applies to the valve gear, with all Walschaerts pivots on roller bearings and mechanical lubrication of the expansion link - dieblock rubbing surfaces (a standard fitting on the SAR 25 Class). Therefore your inference that any higher capital cost of Caprotti gear would be saved by reduced maintenance charges is incorrect. The reason for this is that you are basing your argument on the piston valve design prevalent on BR in the 1950's. But, as you know, the 5AT will not have such valves, therefore any argument based on them is not valid

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**John Duncan's Comment 3**

> British Caprotti valve gear was not specialist equipment. Camboxes and the poppet valves were standard. The cylinders could fit on the left or right hand sides. The drive shafts were standard Hardy-Spicer carden shafts with standard universal joints

**Wardale's Response:** Compared to piston valves and Walschaerts gear, Caprotti valves *were* specialised equipment. Saying the equipment was "standard" is not the point. By "specialised" is meant requiring an engineering effort to produce it that was higher (i.e. more sophisticated) than that required for piston valves because of greater precision, special materials, specialist manufacture in the case of the cams, etc. In this sense ‘standard’ components could be specialised.

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**John Duncan's Comment 4**

> BR standard ‘5’ with British Caprotti valve gear took 1.87 HP in full forward gear to drive the valve gear on both cylinders (BR test results on 73154).

**Wardale’s Response:** 'BR5 Caprotti gear took 1.87 hp to drive in full forward gear'. Power being a function of speed, this figure is meaningless without giving the speed at which it was measured: full forward gear suggests low speed, in which case the figure would not be valid for normal running speeds. See also point (5) following.

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**John Duncan's Comment 5**

> I do not have the calculations for the proposed Porta-type piston valves for the 5AT locomotive. As described, the piston valves might be lightweight, the drag on the valve must be enormous with eight valve heads at 175 mm (6.9") diameter piston valves at 75 mph, 5.69 revolutions per second, on the 1880 mm (6' 2") diameter driving wheels.

**Wardale’s Response:** "The drag on the [Porta-type piston valves] must be enormous." False. The drag on this design of piston valve is actually less than on former designs: to understand this you have to read and understand Porta's papers on the subject - FDC 4 Refs. (4) and (11). If the drag on the four valves of such classes as the Castles, Kings, Lord Nelsons and Stanier Pacifics were "enormous" how could these locomotives, all of which had less cylinder power at high speed than the 5AT, have attained high speeds, which all did? If the drag on Porta type valves were high it means friction would he high, and the extremely low wear rates leading to the extended attention intervals given in (2) above would not have been achieved. In fact the 5AT power loss due to valve ring friction has been calculated: at maximum drawbar power, which occurs at some 26% cut-off and 113 km/h (71 mph), it is 4.9 kW (6.6 HP) for all valves combined (FDC 4 (133)). This is only 0.2% of the cylinder power the 5AT would be developing at these conditions (2380 kW (FDC 1.3.F (17)) and is not "enormous".

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**John Duncan's Comment 6**

> The piston valves are not supported by a valve spindle with bushes at either end. It reminds me of the connection and floating lightweight piston valves on the unrebuilt Bullied Pacifics with wear in the connecting pins resulting in valve over travel.

**Wardale’s Response:** The 5AT valve design should not be compared with Bulleid's valves. They are not the same thing. The valves rest on the liners without tail rods to give virtually 100% steam tightness - impossible with a rigid spindle and bushes - yet at the same time achieve the very low wear rates already indicated (based on actual experience with 3450). The quasi-indefinite maintaining of steam-tightness (as measured on 3450) is the reason why these valves have such a long period between attention. The only pins not on roller bearings (which have effectively zero wear) are those coupling the valves to their spindles. This type of pin was used on the Rio Turbio 2-10-2s and on 3450, and on these locomotives gave negligible wear.

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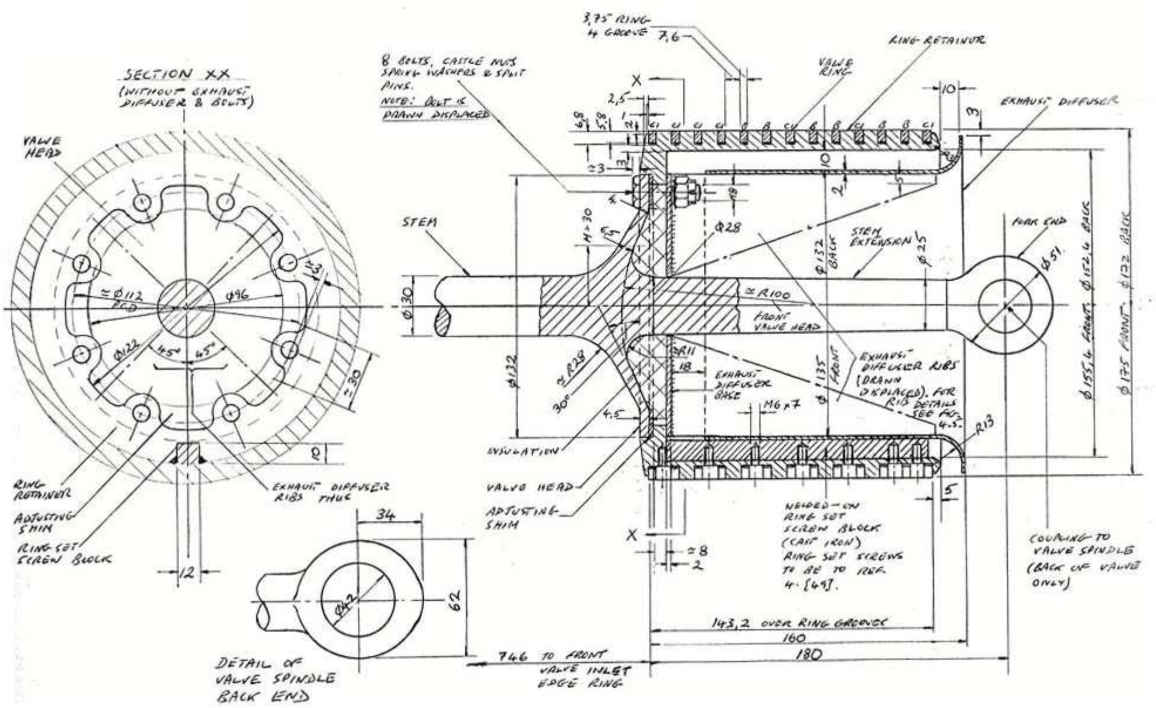
**John Duncan's Comment 7**

The proposed 5AT piston valve, 4 per locomotive 13 piston valve rings per valve head. 104 piston valve rings per locomotive. How secure is the pin in the fork end that cannot be seen?

FIG. 4.4. PISTON VALVE: DETAILS

CONSTRUCTIONAL DETAILS ARE SHOWN APPROXIMATELY ONLY.




**Wardale's Response:** "How secure is the pin in the fork-end that cannot be seen?" Obtaining perfect security - such as that achieved with countless millions of i.e. engine gudgeon pins, a similar component - is a matter of correct detail design, which shows the importance of the latter. The issue here is not so much mechanical security, which in this case is relatively easy to obtain, but designing to ensure lubrication by oil in the exhaust steam and at the same time to negate the possibility / effects of carbon deposit between the pin and bush. This is one item where R & D needs to be done as part of detail design, using a simple test rig simulating valve spindle movement and loading and exhaust steam conditions.

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**John Duncan's comment #8** relates to the first paragraph of Wardale's reply to a 2002 letter from Angus Eickhoff in which Wardale wrote:

"The question of Walschaerts versus Caprotti valve gear has been partly dealt with in the reply to Mr. Attewell. To answer Mr. Eickhoff's points, the contribution of Walschaerts valve gear to the balancing issue is negligible as most of its inertia forces are out of phase with those of the main reciprocating masses, and the maximum acceleration (i.e. inertia force per unit mass) of even ultra long travel valves is only some 30% of that of the pistons."

**John Duncan's Comment 8**

> Inside admission piston valves travel in the same direction as the piston and I agree it could be that the maximum acceleration of the 5AT piston valves is probably only 30% of the pistons. What concerns me is the length of the stroke on the two cylinders of the 5AT at 800mm (31.5"). The longest stroke locomotives on BR were the GWR two cylinder locomotives of same wheel arrangement as the proposed 5AT, at 729mm (30"). Even with lightweight motion I doubt permission would be granted to run above 75 mph.

**Wardale's Response:** If balancing is his concern, the FDC's show acceptable balancing can be achieved whilst keeping wheel-rail dynamic augment (hammer blow) at 200 km/h to no more than that of the BR5 at 75 mph (120 km/h). In fact, they show that the reciprocating parts do not require any balancing at all, by the latest American criteria, which would give zero balance weight dynamic augment. Therefore from a balancing aspect the 5AT is perfectly suitable for 200 km/h running. Whether or not this would be allowed is obviously beyond our control.

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**John Duncan's comment #9** relates to the second paragraph of Wardale's reply to a 2002 letter from Angus Eickhoff in which Wardale wrote:

"Although altering the valve events by changing the cams may be convenient on an "experimental machine", the terms of the project mean that the design of the 5AT is in no way intended to be experimental."

**John Duncan's Comment 9**

> The last two ex. LMS class `5's 44686 & 44687, the BR class `5's 73125 to 73154 and the 3 Cylinder, 4-6-2, 71000 were fitted with the standard camboxes and poppet valves, all interchangeable. What Angus meant was you could design the cam profiles and valve sizes for the 5AT performance you require. In time it could be computer controlled, the cut-off & throttle controlled to produce the most efficient out-put.

**Wardale's Response:** Partly answered by (3) above. Using the 5AT data from the FDC's, the late Prof. Hall's *Perwal* program predicts that the 5AT as proposed will meet its performance target, i.e. its piston valve steam distribution delivers the target performance. Which is what is required. Please let's forget about "computer control": to quote from Bulleid, "it's all very well, but it doesn't sound much like a steam locomotive, does it?" In general the throttle is to be fully open when steaming and the cut-off set to maintain the schedule. That's the driver's job, and it is not too difficult.

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**John Duncan's comment #10** relates to the third paragraph of Wardale's reply to a 2002 letter from Angus Eickhoff in which Wardale wrote:

"Chapelon's reservations about piston valves are no longer valid. Porta's invention of valve liner cooling allows higher steam temperatures to be used without lubrication difficulties, and inertia forces are kept at manageable levels by the very lightweight construction made possible by designing the valves according to stress analysis rather than empirical rules. It is also worth noting that Chapelon's final masterpiece, the 242A-1, as well as his aborted 152P design, had piston valves driven by Walschaerts gear. No recourse to poppet valves needs to be considered before the possibilities of piston valves have been fully explored - which is what the 5AT will do."

**John Duncan's Comment 10**

> If the 5AT speeds proposed for service on Network Rails tracks of 113 mph service speed and a maximum of 125 mph, then piston valves are **not** suitable. Only poppet valves are suitable for high speed working. As regards the French 4-8-4 242.A1 rebuild of the Etat Railways 240.101, a 1932 3-cylinder simple with Renaud rotary cam poppet valve gear, the rebuild was started in 1943 and completed in 1946 with Willoteaux double admission and exhaust piston valves as fore-runner of French steam locomotive development. In the case of the 4-6-4 with 7' 2" driving wheels, it was to have Lentz concentric-type oscillating cam poppet valves. The remaining two designs, the 4-8-4 with 6' 4" driving wheels and the 2-10-4 with 5' 4" driving wheels were to have Willoteaux piston valves fabricated in steel plate to minimize weight. The high pressure valves were two sets under the high pressure cylinder of 8.5" diameter (similar to the 5AT). The low pressure valves were to be 17" diameter, weighing 242.5 lbs plus the piston valve rod weighing 40 lbs, total of 282.5 lbs. To quote Chapelon's book 'La Locomotive a Vapeur', the 'Addenda to the 1952 Edition':
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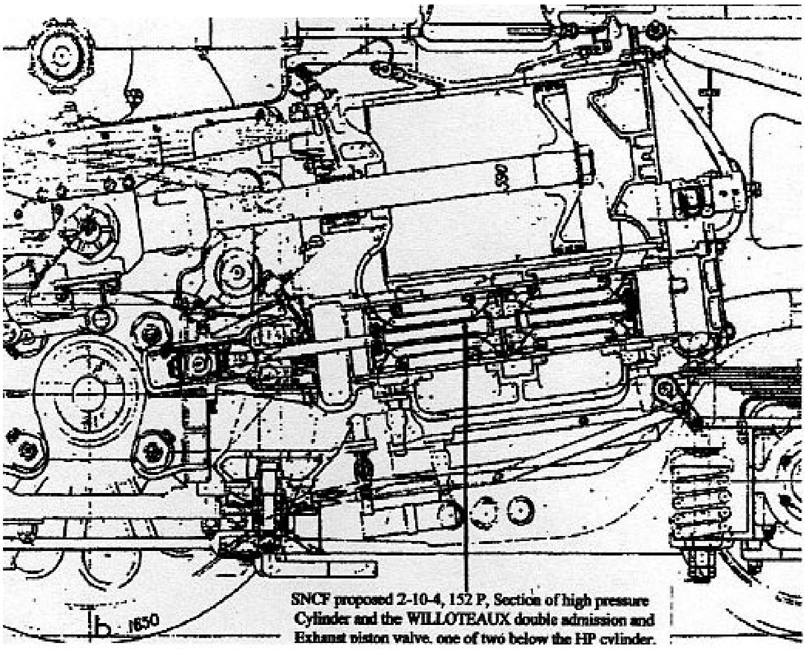
> "For the other three high powered types the use of piston valves rather than poppet valves was dictated largely by workshop and running shed requirements, many of these having experience with piston valves only. However, whilst suitably designed piston valves - Willoteaux with large steam passages - were thermodynamically equal to poppet valves, in practical terms where inertia limitations are important, the poppet valve is far Superior because of its much lighter weight (up to 15 / 20 times less than a piston valve) and much smaller displacement (one fifth to one eighth the travel of a piston valve). Furthermore, poppet valves are superior in their ability to withstand steam temperatures of over 400 degrees for prolonged periods, in which conditions the lubrication of piston valves may be difficult and result in premature wear of piston rings and valve liners with inevitable consequences for steam tightness." - See A. Chapelon, 'La Locomotive 242-A.1' *Revue Generale des Chemins de Fer*, December 1947.



SNCF proposed 2-10-4, 152 P, Section of high pressure Cylinder and the WILLOTEAUX double admission and Exhaust piston valve. one of two below the HP cylinder.

**Wardale's Response:** Chapelon's reservations about piston valves are no longer valid because when he made them he had no knowledge of Porta's advances to piston valve and cylinder tribology design. "Only poppet valves are suitable for high speed working." Completely false. I will remind you that the A4 world speed record holder had piston valves. Yes, the middle valve over-travelled at high speed, but this was not intrinsic to piston valves nor Walschaerts gear, but to the Gresley gear. (The problem of driving the inside valve of a 3-cylinder engine is neatly overcome on the 5AT by not having an inside cylinder, so any advantage of Caprotti gear in this regard is irrelevant.) And the only steam locomotives ever required to sustain 100 mph working in regular service to maintain the schedules, the Milwaukee 4-4-2s and 4-6-4s and the DR 05 Class 4-6-4s, engines of the last two of which were, I think, recorded at 125 mph on test, i.e. only one mph less than *Mallard,* all had piston valves, of the 'first generation' variety, not the much superior Porta type. So your assertion that "only poppet valves are suitable for high speed working" is simply not true, in fact almost the opposite, it could be said that it is poppet valves that have yet to prove themselves suitable for high speed (which does not mean they could not do so.) For example, the possibility of the cut-off cam follower leaving the cam and thereby lengthening cut off at high speed is possible. This possibility is calculable. In the absence of any calculations, you have made an unsubstantiated claim. As far as Walschaerts gear is concerned, it has been proven to work at very high speeds - the above-given examples - but this does not obviate the necessity of a full deflection analysis being carried on the 5AT valve gear, in addition to stress analysis, as part of the detail design, to ascertain what, if any, deviation from the nominal valve motion will occur at very high speed - a meaty task for whoever has to do it. No 3-figure speed has been recorded by steam in this country with a poppet valve locomotive, to my knowledge: all those classes which have (Al, A2, A3, A4, MN, King, Duchess...) had piston valves. The highest speed I am aware of with a poppet valve locomotive is 177 km/h (110.6 mph) during SNCF electric loco pantograph tests in 1956, with a very light load (220 equivalent tons), by a 231E Class with Walschaerts-driven (again!) oscillating cam poppet valves. Chapelon's comments, when analyzed, have no merit for the 5AT. "Inertia limitations": Porta-type valves may well be lighter than anything Chapelon envisaged. At maximum design speed (200 km/h) with coupled wheel tyres at minimum size and using a cut-off of 26%, which is a transitory overload case as this cut-off at this speed would be beyond the boiler's continuous steaming capacity (i.e. absolute worst conditions that might be briefly encountered) the instantaneous peak inertia load per 5AT valve and spindle assembly is calculated as 9,234 N (2,075 lbf) (FDC 5.(250)), which is a quite acceptable figure, this because of careful design to limit the weight of the valves. As the valve acceleration is proportional to the locomotive speed squared, at the maximum continuous operating speed (180 km/h) this falls to 7,480 N (1,680 lbf), and at the maximum speed at which 26% cut-off could actually be sustained according to FDC 1.3 (113 km/h) to 2,948 N (662 lbf). The result is a valve spindle of only 28 mm diameter to take the highest load at an acceptable stress level (FDC 4.(420)), a very modest figure which would not be possible if the valve inertia load were a 'limiting factor'. The examples quoted above of high-speed engines with piston valves are the practical proof that piston valve inertia is no barrier to high speed. "Ability to withstand steam temperatures of over 400 degrees": Chapelon had not foreseen valve liner cooling, which eliminates his objection to piston valves at high temperature. Porta has shown that what counts is liner rubbing surface temperature, not steam temperature. The low wear rates of 3450's valve components (point (2) earlier) were recorded with steam temperatures up to 450' C (842 °F).

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**Note:** John Duncan's comments 11 to 15 relate to a statement by Wardale that appears on this website, saying:

"Because bending stress due to inertia load at maximum speed is greater than maximum allowable crankpin fibre stress, cushioning ***must*** be provided to relieve the inertia load on the main crankpin. Note that this is one reason to reject Caprotti valve gear as finally applied to BR locomotives, as the valves were arranged to drop from their seats during drifting thus providing a full by-pass from one end of the cylinder to the other, precluding the build-up of cushioning steam pressure. The required cushioning steam pressure at dead centre is now calculated for the worst case condition, i.e. maximum speed with minimum coupled wheel tyre thickness, this pressure being therefore suitable for all lower coupled wheel rotational speeds ....."

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**John Duncan's Comment 11:**

Ans 1: Reference "Locomotive Management from Cleaning to Driving" by Jas. T. Hodgson M.I.Mech.E. sixth edition. Page 221. Quote:

"PISTON VALVES are almost invariably adopted by superheated steam locomotives, and particularly when these are of the non-collapsible pattern, an objectionable knocking is set up at the crosshead pins and the small and large connecting rod bearings when running without steam.

Knocking at the crosshead pins is caused by the inertia forces of the reciprocating parts being taken up by a cushion of air compressed behind the piston towards the end of the stroke, which cushion of air is suddenly released when the port opens to admission, thus throwing the inertia forces on the crank and crosshead pins on the opposite side to that on which they had before been applied when the moving parts against the air cushion."

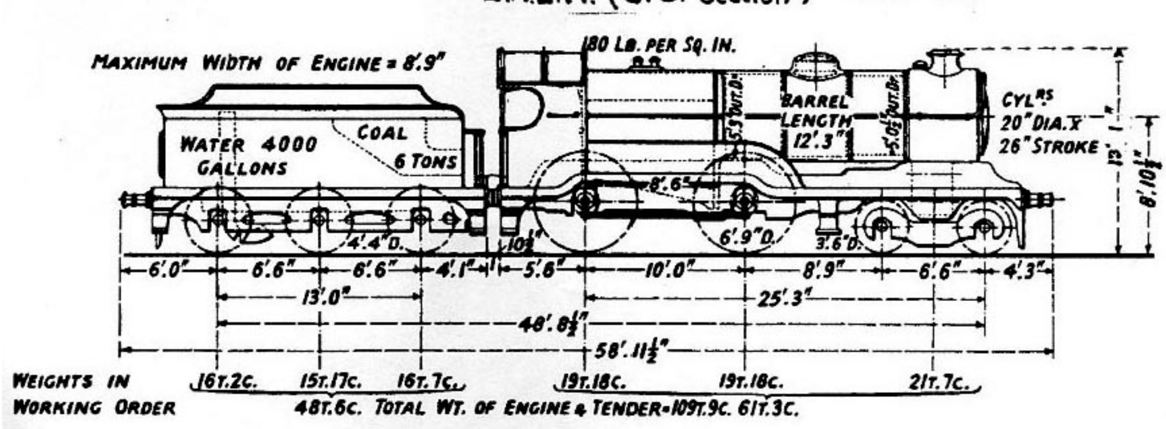
It goes on to explain that to overcome this by the following:

**By-pass valves**, The LM&SR (Midland Division) fitted by-pass valves to their class 2P and 3P, 4-4-0's for the long downhill runs on the Settle and Carlisle route. On the LM&SR (Northern Division) the ex. Highland Railway fitted by-pass valves under the cylinders of their locomotives for free downhill running on the Inverness to Perth mainline.

**Automatic By-pass Piston Valves**. Five locomotives of the ex. GCR class 11E after they became LNER class D 10 4-4-0s, were converted to Trofinoff automatic by-pass (TAB) piston valves, (outside admission and short travel) between 1935 and 1938. The valves were 10" in diameter.

In November 1948 during my engineering apprenticeship on the valve section of the machine shop in Gorton Locomotive Works BR(E), I worked on overhauling a pair of TAB piston valves. The piston rods had a constraint in the middle and the piston valve-heads slid on to the spindle from each side. When steam was applied to the cylinders the two heads were pushed on to the centre constraint. When the regulator was shut the heads moved to each end of the steam chest allowing each side of the piston to be connected, giving full bypass with free running. At that time 62653 was being fitted with new cylinders and I had the job of trying the piston valve heads with rings fitted in the new valve liners in the Erecting Shop.

L.N.E.R. (G.C. Section) 'Director' Class




Class D10 (11E)

British Caprotti poppet valves operate as by-pass valves when the regulator is shut.

All above is the opposite of Wardale's statement in FDC 3, item 137, on piston valve locomotives without a by-pass, the regulator has to be cracked open when running downhill, and they are not ‘free running'.

**Wardale’s Response:** Drifting: Your quote from '*Locomotive Management'* (a book not anticipating 200 km/h locomotives): " ... a cushion of air...". Air must definitely not be present in the cylinders as it oxidizes cylinder oil. It is one function of drifting steam to ensure this. It is claimed that knocking is overcome by by-pass valves, of which there are a great many designs, most of them ineffective (including Trofinoff valves, used on Chinese locos and a very poor design.) But on a locomotive with roller bearings on the crossheads and crankpins, as the 5AT would be, there is no knocking. 3450, with Porta-type piston valves and no by-pass valves, gave no knocking at the crossheads, crankpins or axleboxes, from one overhaul to the next. So this point does not apply. Caprotti valves as finally used on BR do operate as by-pass valves with the throttle shut: but (1) you yourself have told me that big-end wear was greater on Class 5's with Caprotti gear than with Walschaerts gear, suggesting the benefit of compression in relieving the inertia load on the crankpins, and (2) as FDC 3(137) correctly says, cushioning *must* be provided on the 5AT, and the drifting steam is necessary to achieve this (FDC 3 (148)). Put another way, if Caprotti gear gave a full bypass, the inertia load at maximum speed on the 5AT would overstress the main crankpin and probably lead to rapid fatigue failure. The criteria for running at 200 km/h are much more severe than those for the examples which you give, and for the *5AT cushioning is not an option, it is a necessity.* Drifting steam and the absence of a by-pass are therefore also necessities. The comment about the design not being `free-running' is irrelevant in this context, as even if Caprotti valves were to be used (1) they would have to be arranged to provide no by-pass and (2) drifting steam would have to be supplied to give cushioning, i.e. the same as with piston valves.

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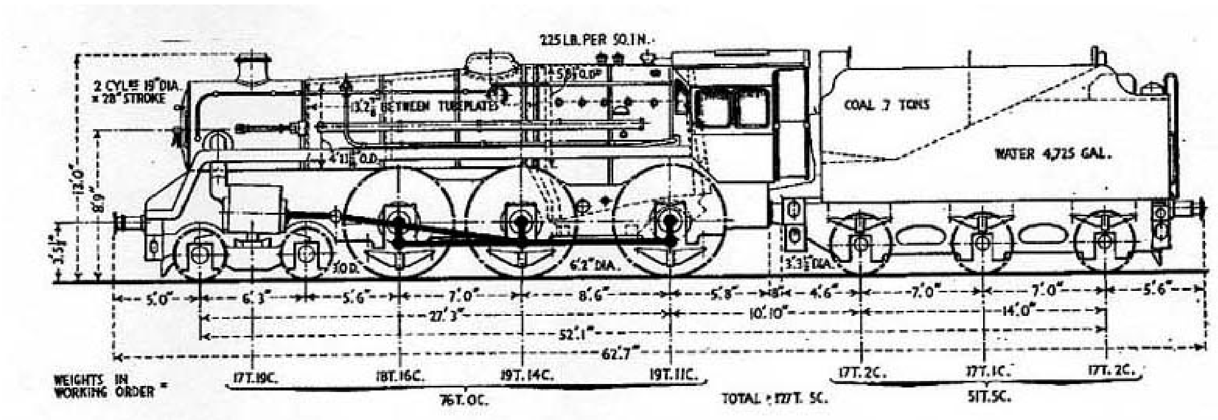
**John Duncan's Comment 12**: *Wardale goes on to state …….. other reasons are:-*

**Cost**; (See previous answer). Initial first cost is 10% more than the piston valve B.R. Std. Class 5 for 30 locomotives out of the remaining 142 piston valve locomotives, a small cost for the substantial savings made on the 30,000 to 35,000 miles piston and piston valve examinations.

With British Caprotti poppet valve gear the inspections were done at major overhauls in the main workshops - at 180,000 to 201,000 miles in the case of the BR Std. Class 5 73125 to 73154.




**Wardale’s Response:** ‘Higher initial cost of Caprotti gear is a small price to pay for the savings made on valve examinations at 30,000 – 35,000 mile intervals. Caprotti inspection was done at major overhauls at 180,000 – 201,000 miles.’ Your argument is not valid because it is based on BR piston valve performance, not that which will be achieved by the 5AT. Point (2) earlier shows that the Caprotti inspection period you give can be achieved with piston valves, so if any extra cost were to be incurred for the Caprotti gear it would bring no benefit in this regard.

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**John Duncan's Comment 13**:

Savings were made operating in ‘free running' downhill.

**Wardale’s Response:** Savings due to ‘free running downhill’. Point (11) above shows that drifting steam would be mandatory on the 5AT, whatever type of valve were used. ‘Free running’ will have placed the full reciprocating mass inertia load on the main crankpins, and this will have been at least a contributory factor in the higher wear of the big end bearings that you observed on the Caprotti Class 5s, thereby diminishing by increased maintenance cost any saving made on the road.

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**John Duncan's Comment 14**:

Savings were made with full regulator at cut-offs as low as 3% to 5%.

**Wardale’s Response:** ‘Full regulator at cut-offs as low as 3% to 5%’. Full regulator, very short cut-off working was also used with (first generation) piston valves, e.g. A4s did much of their work at 10% cut-off or less. Porta has shown the features necessary of a piston valve to obtain good results at short cut-offs, features not found in BR valves, so ultra short cut-off working is practical with such valves - I have driven 3450 myself in mid gear (5%) on a 570 ton passenger train. Due to unwanted heat transfer effects *(i.e. condensation)* such very short cut-offs did not produce the most economical working with FGS. However the 5AT cylinders as a whole will have design features to maximise the benefit of short cut-offs. Ultra-short cut-off (say < 10%) inevitably produces relatively little power, and as the 5AT would be expected to operate mostly at high power to maintain high speed, such cut-offs would probably be used for only a small fraction of the operating time.

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**John Duncan's Comment 15**:

> Savings on lubricating oil costs were considerable compared to the piston valve locomotives of the same class. I did a study on this subject for Mr. Rhyll, the District Motive Power Superintendent of the 6A District in May 1960. The piston valve locomotives were 28% higher than the Caprotti locomotives in cylinder oil consumption.

**Wardale's Response:** Lubricating oil saving. This is accepted, but even here there is a reservation, in that oil fed directly to the cylinders tends to be ineffective, much of it going straight to exhaust, the cylinders relying a good deal on valve oil carried in inlet steam for their lubrication. Therefore a low valve oil feed may result in higher cylinder liner and piston ring wear.

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**John Duncan's Comment 16 -** *Quoting Wardale: "It is specialist equipment";*

> Not on British Railways. If steam locomotives had continued, the British Caprotti valve gear would have become standard for most large locomotives, with standard cam boxes & poppet valves.

**Wardale's Response:** 'Caprotti valves not specialist equipment on BR.' Answered in point (3) earlier: your point is based on misunderstanding the use of the word 'specialist'.

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**John Duncan's Comments # 17**

> E.S. Cox states in his book 'British Railways Standard Steam Locomotives' page 112: 'the ultimate British Caprotti system was thoroughly workman like, and its extended use would have been practically certain had steam continued'.
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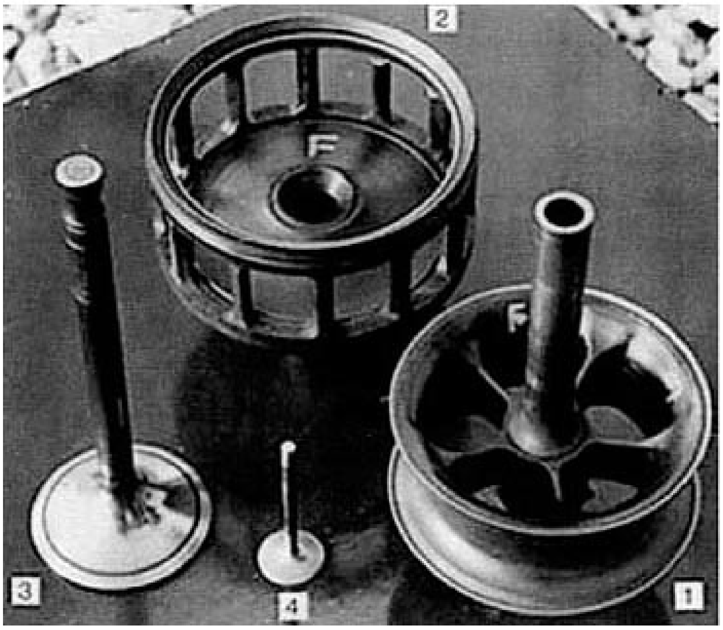
> R.C. Bond states in his book "A Lifetime with Locomotive" page 246: "These thirty engines, one of which, 73154, was the last steam locomotive to be built at Derby, turned out very well. There is, I think, little doubt that had steam continued longer, poppet valves would have supplanted piston valves, at any rate, on higher mileage locomotives".

**Wardale's Response:** Quotes from Cox and Bond: irrelevant, as they are based on piston valves as they knew them, not Porta valves.

**John Duncan's Comments # 18 -** *Quoting Wardale: "Less than 100% certainty about steam tightness and good flow coefficients past double beat poppet valves".*

British Caprotti poppet valves and their cages have two seats, one flat and one tapered, so the valve cage and double seat poppet valve expand at the same rate always maintaining their steam tightness. When open steam can pass round the outside and through the hollow inside of the poppet valve, giving greater opening for the steam flow than the piston valve and no 'wiredrawing' on valve closure.




1. **Caprotti poppet valve** (Steam passes through the middle and outside when open).
2. **Caprotti valve cage** (Expands equally with the poppet valve).
3. **Sulzer diesel engine poppet valve.**
4. **Rover car petrol engine poppet valve.**

**Wardale's Response:** Steam tightness. That Caprotti valves may have solved the suspect steam tightness issue by the design shown is tentatively accepted, although this needs confirmation by tests (as made on SAR 25NC and 26 classes, see *The Red Devil* pages 316-321: such a test could presumably be carried out on 71000 - why not investigate this?) This being the case, it no more than brings poppet valves up to the standard of Porta piston valves. Very long lap Porta-type piston valves as specified for the SAT will minimize 'wiredrawing', which is present to some extent with *any* valve, whether slide, piston, or poppet, see point (20) below. In this regard an independent observer has made the point that at high speed and short cut-off the indicator diagrams produced by 3450, as given in *The Red Devil*, are as good as those of 71000, showing the thermodynamic equivalence of the two, as noted by Chapelon in your quote. And the 5AT will be (much) better than 3450 in this regard.

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**John Duncan's Comment 19:** *Quoting Wardale: The fact that the piston valve for the 5AT will in all respects (e.g. steam flow, lightness, lubrication, wear, resistance to high steam temperatures, resistance to steam leakage) greatly superior to the general level of piston valves in the past with which Caprotti valves have been compared;*

> The list above under e.g. is all the advantages of British Caprotti poppet valve gear has over piston valves and more. Even with the advantages proposed by the 5AT piston valves might be lighter in weight but the lubrication required for 104 piston valve rings per locomotive must have a high oil consumption compared to no lubrication on British Caprotti poppet valves, which remain steam tight due to the unique system of the valve seats being in a cage and the poppet valve having two seats one flat and one coned. The valve and cage expand and contact together, remaining steam tight overhaul to overhaul.

**Wardale's Response:** Valve lubrication requirements do not depend on the number of valve rings. There would be no difference for 2 or 20 rings per valve. No lubrication for the valves may have a detrimental effect on cylinder liner and piston wear, see (15) earlier. The Caprotti valves themselves have no lubrication, but the camboxes do, and in fact Figs. 105 and 106 in my copy of *Locomotive Management,* illustrating the arrangement of Caprotti gear, show a number of lubrication points.

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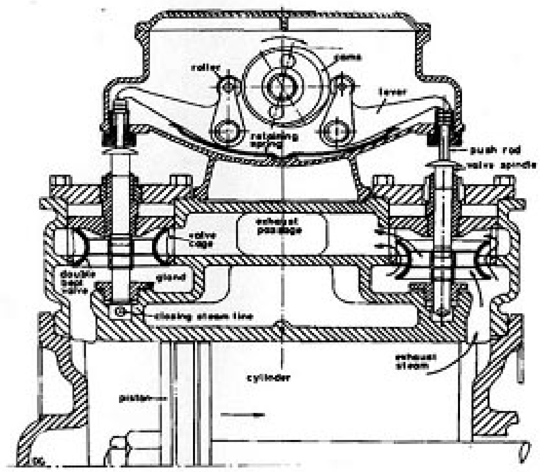
**John Duncan's Comment 20:** Other advantages are: -

1. Resistant to very high steam temperatures.
2. Allow steam to flow freely through the middle and outside of the poppet valve.
3. Inlet and exhaust events are separate.
4. Optimum valve events can be designed into the four cams in sealed cam boxes.
5. Complete bypass when the regulator is shut, allowing free running.
6. There is no alteration in valve timing by the movement of wheels and axleboxes in horn ways.
7. Inlet valves are smaller than exhaust valves giving free flow and reduced back pressure which cannot be done with piston valves. (71000's inlet valves are 6.25" diameter & 0.796875" lift, exhaust valves are 7" diameter & 1.078125" lift).

Arrangement of the British Caprotti exhaust poppet valves




**Wardale's Response:** Other advantages:

1. Resistant to very high steam temperatures: no advantage over piston valves with cooled liners. It is true that no cooling needs to be provided with poppet valves, but it is simple to manufacture with no moving parts and hence gives negligible capital and maintenance cost increase.
2. Irrelevant as an advantage, it is merely a feature.
3. Inlet and exhaust events are separate. True, but what does this really mean in terms of higher cylinder efficiency? This must be quantified for an advantage to be claimed. To repeat from (18) above, the indicator diagrams produced by 3450 have been judged to be as good as those of 71000, and the 5AT will be much better.
4. Irrelevant as an advantage, it is merely a feature - we might just as well say that optimum valve events can be designed into the Walschaerts gear.
5. As explained in point (11) earlier, this is no advantage for the 5AT.
6. True, but what effect does this really have on Walschaerts gear - with poorly laid track at depots there may be some (barely) measurable effect, but with near-perfect high-speed track - which is where the 5AT would operate - it will be negligible. Therefore this would be an advantage on paper only, and in any case you must quantify the actual improvement in cylinder performance before you can claim any advantage for Caprotti gear.
7. There is no net advantage of poppet valves in this regard. It is a major function of piston valve lap to give greatly increased flow past the valves to exhaust steam compared to inlet steam, compare *The Red Devil* Figs. 48 and 50. On poppet valves the larger exhaust valves with higher lift merely give the same effect, but to a lesser degree. The question of valve opening merits some investigation. From the data you give for 71000 (and it is interesting to see that valve lift can be specified to one millionth of an inch!), the nominal valve openings at full lift, for the upper and lower seats combined, are 201.9 $cm^2$ per valve for the inlet valves and 305.9 $cm^2$ for the exhaust valves, with no allowance for the

flow obstruction caused by the valve cage bridge bars. But these are clearly not the true limiting openings concerned. To go to or from the upper seat steam must pass through the annular space at the centre of the valve, and that passing the lower seat must go through the annular gap between the valve body and the cage, both of which are smaller than the respective nominal openings: this is clear from the valve on the right of your figure. Scaling the various diameters from your figure, and allowing a 10% reduction in the central flow area due to the valve ribs, gives the following minimum combined flow areas to/from the top and bottom seats, per valve, which are the effective valve openings at full lift (nominal maximum opening): inlet valves ≈ 147 $cm^2$, (27% less than nominal opening), exhaust valves ≈ 185 $cm^2$, (40% less than nominal opening). Note that these are independent of valve lift, which is why the exhaust opening is reduced the most - the extra lift of the exhaust valves is of no advantage to the minimum flow area. The moral is that a large nominal opening is wasted if the steam flow to or from that opening is restricted, which is the case. Added to this is the possibility of a relatively poor overall flow coefficient past the valves due to somewhat indirect steam passages with some sharp-edges. These figures may be compared with those for the 5AT, calculated from the FDCs, particularly Appendix 1 of FDC 5 giving the valve events. Selected maximum admission openings through the valve liner ports per cylinder (i.e. for two valves, average of front port and back port) are: 75% cut-off (full forward gear) = 491 $cm^2$, 30% cut-off ≈ 134 $cm^2$, 20% cut-off ≈ 94 $cm^2$, 10% cut-off ≈ 65 $cm^2$. Maximum exhaust openings: in mid gear (4.8% cut-off) ≈ 442 $cm^2$, rising to 491 $cm^2$ by 25% cut-off and remaining constant thereafter up to full gear (as the valve fully uncovers the liner port). This analysis is exploratory and approximate as it does not consider all factors involved, which have pros and cons for both piston and poppet valves, but it does allow qualitative conclusions to be drawn. It shows that the maximum exhaust opening of the 5AT's piston valves is (considerably) higher than that of 71000 at all cut-offs. The inlet valve opening is also higher down to somewhat above 30% cut-off. Thereafter the advantage lies with the poppet valves. The extent of this advantage at very low cut-offs, where the cam profiles may not give full lift of the valves, making the nominal opening less than 147$cm^2$, cannot be ascertained. All-round the advantage lies with the piston valves. The exhaust opening is most important, because it is harder to exhaust steam quickly than to admit it, due to its low pressure. (This does show, incidentally, that any tendency of Caprotti valves to give high peak draught will be accentuated on the 5AT. which would be very destructive without features such as the Kordina, oil firing, and special attention to brick arch security.) During inlet, it is hardest to minimize the admission triangular loss on the indicator diagram when cutting-off around the middle of the stroke, where piston velocity is highest, and here the advantage also lies with the piston valves, which will, for example, assist in good acceleration through the mid cut-off range. Although the piston valve admission area is less at low cut-offs, (1) by definition the quantity of steam to be admitted per stroke is then low and (2) the piston is moving relatively slowly, so that keeping full pressure on the piston head is easier than around mid-stroke. Which means that the lower valve opening area here is not such a disadvantage.

**John Duncan's Comments # 21 -** quoting Wardale: "*Lastly (from the view of the projects aim, not least). Walschaerts gear is aesthetically more attractive."*

> Well! What can I say? Cost and efficient use of steam from the boiler is the aim, not the looks of Walschaerts Valve gear.

**Wardale's response:** "Cost and efficient use of steam from the boiler is the aim, not the looks of Walschaerts valve gear". Firstly, the piston valves and valve gear as specified for the 5AT will give as efficient use of money and steam as Caprotti valves, if not better. Secondly, the looks of Walschaerts valve gear *do* matter, to me at any rate. The purpose of the 5AT is to keep the aesthetic spectacle of main line steam in the UK alive. Full stop. That was the only reason for proposing it. If members of the 5AT group seem to have lost sight of this, or perhaps never had sight of it, that is their misfortune, as it causes them to go in wrong directions. But I have always worked for steam with the sole purpose of keeping it alive as an aesthetic spectacle, and all other things (engineering, efficiency, economics etc) have only been tools to this end. So I don't lose sight of the aesthetics, which is why, for example, the front streamlining does not extend down to near rail level like on the DB 10 class, as it should do for good aerodynamics. But it simply makes it look wrong, in my eyes, and it's my eyes that count, up to now anyway. Walschaerts gear does look better than Caprotti, the awkwardly-angled drive shafts beings very unaesthetic. And in accordance with the *raison d'être* of the 5AT, this is a reason to prefer it. Fortunately the engineering, performance, and aesthetic reasons coincide.

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**John Duncan's Comment 22:**

> I remember as a fitter on steam locomotives, the amount of wear on the die block and in the expansion link with a mixture of oil and brake block dust in the normal cut off position on Walschaerts valve gear. Not as much on Stephenson expansion links on ex-GW locomotives with the valve motion inside the frames of the locomotive.

**Wardale's response:** Amount of wear of dieblock and expansion link. No longer an issue, with the application of mechanical lubrication to these parts, as per SAR locomotives.

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**John Duncan's Comment 23:**

> I went out in 1960 as relief fitter from Chester MPD to North Wales depots on the footplate and rode on LMS and BR class 5's, both piston valve and Caprottis. I noted on the piston valve locomotive was driven in first valve on the regulator and 30% to 35% cut-off, if notched up to less than 20% cut-off and the regulator opened to `full' resulted in a lot of vibration from the motion. Coasting with the regulator `shut' a knocking noise was set up in the big and little ends, so the Driver had to crack open the regulator to stop this happening.

The driving technique on the Caprotti fitted locomotives was different. Once under way it was 'full' regulator and a fine cutoff sometimes a low as 3% to 5%. Every exhaust beat could be heard, sharp and clear. No banging or shaking on the footplate and just the noise of the rail joints when coasting. It's called 'expansive working', save coal, water and cash!

**Wardale's response:** Piston valves are no barrier to short cut-offs, see (14) earlier. Do you think Gresley Pacifies were not worked at less than 20% cut-off? Please reread C. J. Allen and 0. S. Nock. Do not extrapolate a problem with the engines you rode on to include piston valve engines in general, and certainly not the SAT. No knocking *of any kind* can be guaranteed from shopping to shopping when roller bearings are fitted throughout and Franklin wedges on the driving and coupled axleboxes. No loss of exhaust beats even down to the smallest cut-offs with Porta type long lap valves (experience with 3450, and even 19D 2644 which had only elementary alterations to the standard SAR piston valves). "Every exhaust beat [on a Caprotti engine] could be heard, sharp and clear" - and probably pulled the fire to pieces, on 71000 anyway (sorry for that one!) I do know what 'expansive working' is: even normal piston valves have delivered it in the past. Nevertheless Porta valves with longer lap than prevalent in former times greatly increase their capacity to do so.

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**Comment 24:** *Passage photo-copied from Chapelon's Locomotive a Vapeur as follows:*

**POPPET VALVES** are necessary:

1. On locomotives with very high superheat to avoid the necessity for lubrication of admission ports of piston valves and thereby to protect the oil from cracking effects and to allow it to retain its functional value as a lubricant. For this reason it is simpler to lubricate a poppet valve locomotive than one with piston valves.
2. Because the weight of a double beat poppet valve of the type now used is infinitely less, for a given cross sectional area of steam passage, than that of a piston valve even when the latter is of the lightest type in welded plate.

Now, when it is required to build a large compound locomotive with very large cross sectional areas through the l.p. valves this can be done, even on the largest locomotives, with poppet valves of which the moving parts weigh only 4-5 kg. whilst comparable piston valves would weigh more than 100 kg. Furthermore, the poppet valve only needs to be raised from its seat by about 30mm, equal to one eighth of its diameter, to provide the required cross-sectional area, whilst it is necessary to provide piston valves with a travel of the order of 200mm. This makes very clear the infinitely smaller inertia forces arising with poppet valves compared with those for piston valves.

Thus, with poppet valves one can achieve the largest cross sectional areas for steam passages to l.p. cylinders, even at the highest speeds, without fatigue in the distribution mechanism which cannot be achieved with complete safety with piston valves.

This has been confirmed clearly by experience, numerous incidents having occurred in l.p. valve gear with long travel piston valves or those of very large diameter, whilst such problems have not arisen with poppet valves.

The drop piston valve has the same advantages as the poppet valve from the inertia viewpoint, but it does incorporate valve rings and in terms of wear and lubrication is in the same situation as ordinary piston valves.

*All recent experience has shown. that the principal improvements to the steam distribution systems of locomotives have been in the increased cross sectional areas open to steam in its passage through the valves.*

**Wardale's response:** Quoted passage from Chapelon, *La locomotive à Vapeur*.

1. Piston valve lubrication is normalised at high steam temperature by lubricant feed direct to the valve liners and by valve liner cooling.
2. Weight: what counts is the inertia load produced by a valve on the valve gear: it has been shown in point (10) earlier that this is low with the piston valves of the 5AT, hence the point is irrelevant in this case.
3. Quote: "when it is required to build a large compound locomotive..." The 5AT is neither large nor compound, so again the arguments do not apply here. They may become relevant in the case of a large high-speed compound design, but a valid decision in this matter could only be made by calculations for both types of valve. In such a case there is the option of cushioning piston valve inertia, as investigated by Porta but not required on the 5AT. Chapelon gives 100 kg weight for a piston valve: the 310 mm diameter 55 mm lap 24 ring valves for 3450 weighed 67 kg, with rings and spindle, with perfect mechanical reliability. The *two* such assemblies per 5AT cylinder are calculated to weight 54.48 kg (FDC 4.(442)), so Chapelon's figure simply does not apply.
4. Chapelon's further comments about the ultra large valves needed for compound l.p. cylinders do not apply as the 5AT is not a compound.
5. The last sentence in italics is agreed with, and the design of the 5AT fully complies with it, due to having a collectively large circumferential valve liner port area, very long valve lap, good flow coefficient, and minimum cross sectional area of the valve liner bridge bars. Lastly, it can be noted that the French chose piston valves instead of poppet valves for their last express steam class, the (large, compound) 241P's of 1947.

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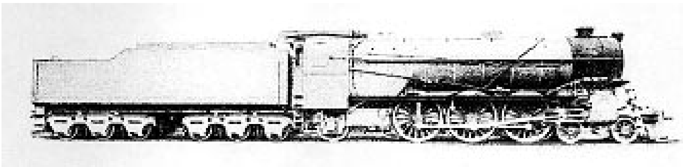
**John Duncan's Comments # 25 -** *Quoting the following passages from Porta.*

**Ing. L.D. Porta - Piston Valves vs. Poppet Valves**

**Why did the Argentine Railways choose poppet valves instead of piston valves for their standard express passenger steam locomotives in the 1950's?**



*Former Central Argentine Railway Company (Now Bartolome Mitre Railway) Class PS 11, 3 cylinders, 4-6-2.* So successful was this locomotive design that upon the Nationalisation of the Argentine Railways, the Authorities decided to standardize the PS 11 class for express passenger service on three railways, the Roca, the Barolome Mitre, and San Martin Railways. The Vulcan Foundry in England supplied 50 additional locomotives with the new version of British Caprotti rotary cam poppet valve gear during 1950 to 1953. Gauge 5' 6", driving wheels 6' 2½" diameter, cylinders (3) 19.5" diameter x 26" stroke, Boiler pressure 225 psi, tractive effort at 85% boiler pressure: 38,068 lbs. The PS 11s hauled a maximum of 750 tons and 500 ton trains at an average of 67.5 mph, running at 100mph on occasions. They were free running because of the poppet valves falling of their seats when the throttle was shut allowing bypass from both ends of the cylinders.

From:- Ing. L.D. Porta's Paper, Fundamentals of the Porta Compound System for Steam Locomotives *(first circulated privately in October 2000)*

1. Introduction - 4th Paragraph: "When the Author started his locomotive design exercises, they were very much based on the *famous* ex-FCCA (Argentina) PS 11 single expansion, three cylinder *Pacifics* with Caprotti poppet valves, whose performance was much superior to the older PS 8: double heading was eliminated!"

2:1 Leakage, 3rd Paragraph: "Poppet valves are heavy offenders where leakage is concerned. The various claims against this statement have never been sustained by measurement or serious reasoning. Chapelon measured heavy leaks as reported in his book, (*La Locomotive a Vapeur,* Bailliere et Fils, Paris 1938.) The reason is that, except in the CAPROTTI gear, the valves seat on the cylinder block, itself subjected to widely different (and varying) temperatures, and hence distortions. This aspect is so important that Stimpf developed elastic seats, and the corresponding theory for them. (STUMPF, J. *Die Gleischstrom - Dampfmaschine,* Dritte Auflage, Druck von R. Oldembourge, Munchen 1922).

*Quotation from Ing. L.D. Porta's paper on; "Fundamentals of the Porta Compound System for Steam locomotives", included in "Advanced Steam locomotive Development", one of three technical papers by Ing. L.D. Porta, published by Camden Miniature Steam Services.*

## Appendix D. POPPET vs. PISTON VALVES

This appendix has been written with the Author himself as addressee. Therefore, the intention is not to present proof for any aspect which is itself deserving of a thorough discussion elsewhere.

The controversy is between poppet valves incorporating a number of proposed improvements, and the Author's piston valve design.

It is claimed that poppet valves can provide a fine adjustment for the valve events: this potential advantage cannot be made actual if the decision for the optimum valve events is poorly defined.

Poppet valves do leak considerably, even if in stationary tests no steam appears at the cylinder cocks. For example, DABEG valves sit against the cylinder block, but the latter is subjected to considerable distortions under the effect of superheated steam. Stumpf realised this and developed elastic seats. CHAPELON measured considerable leakage for the poppet valves, far more than the author measured for his piston valves.

The valves are very expensive to manufacture from a solid special steel forging and cannot be repaired in the event of breakages. These come about because the contacting velocity at the moment of closure must be limited. A significant improvement is brought about by duplicating the number so as to have smaller valves (FRANKLIN).

The mechanism for valves such as CAPROTTI, FRANKLIN, COSSART, RC and others is precision made, hence expensive to manufacture, and is not immune to wear. When this occurs, the precision is lost, and so also is the initial valve setting, with an uncertain loss of performance - the Author's piston valves, on the other hand, are guaranteed to give full power and economy from shopping to shopping. In the case of poppet valves, expensive spare parts need to be considered, as is the case with diesel engines. All in all, poppet valves, even if improved, ARE NOT HEAVY DUTY EQUIPMENT.

**Wardale’s response:** Quoted passages from Porta.

1. Why did the Argentine Railways choose poppet valves instead of piston valves for their standard express passenger steam locomotives in the 1950's? Well, they didn't, really, the PS11 was an already existing class that was simply duplicated. It could well have been that their Caprotti gear was indeed found better than the piston valves driven by Walschaerts gear on plain bearings, each one with an individual oil cup, that they were then using, which has no relevance to a comparison with Porta type valves as subsequently developed, driven by Walschaerts gear on roller bearings.

   The standard locomotives they purchased after the war for the Belgrano Railway, for example, including passenger 4-6-2's, all had piston valves. If quantity were the criterion, piston valves would easily be the winner. And I do question the accuracy of the clip you quote from: for example, the Roca Railway used a different type of 4-6-2, the 12(E?) Class with piston valves, by memory (Atkins writes of the PS11's on page 89 of *‘Dropping the Fire’*, "many of these evidently saw little service on those lines previously unfamiliar with poppet valve gear.") And the possibility of trains travelling at 100 mph on Argentine track without leaving the rails is positively unbelievable, and I am more than skeptical that it ever happened. I made an extensive tour of the Argentine railways in 1973, when steam was still much in evidence, and no PS 11s were to be seen.

2. That the Caprotti design may have overcome the leakage problem has been accepted, point (18) earlier.
3. The quote from Porta, "Poppet vs. Piston Valves" is not an advert for the former. Rather the reverse, as you would expect!

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**John Duncan's Comment 26:** *Quotation from Locomotive Post (date not legible)*

**CAPROTTI PERFORMANCE By P. FRASER**

THE articles on the British-Caprotti Valve Gear which have appeared in this paper have given valuable information on the parts and layout out o£ the gear, but possibly many are wondering how it performs under working conditions. As I have had the good fortune to work one of the L.M. Class 5 engines fitted with this gear, my experience may be of interest.

This was the first time I had been on one of these engines, but I found it simple and easy to handle. In fact, throughout the 115 miles run, on rising or falling gradients or on level track, the performance was highly satisfactory. Cut-off is variable between 70 per cent. and 3 per cent, and I found that it really works at 3 per cent.

Starting was carried out cautiously and a trifle apprehensively, but once clear of the station and with the throttle wide open, as per instructions, all doubts were dispelled by a display of remarkable acceleration. Due to the by-pass effect caused by the valves dropping off their seats when the throttle is closed, the engine coasts with complete freedom. Full advantage was taken of this to coast over 40 miles in stages between Glasgow and Carlisle. At all times absence of noise was noticeable, but when coasting, even at high speeds, the quiet, smooth running of the engine was impressive. The reverser may be used in the same way as any other except that reversal from one gear to the other is not completed until it has been placed in full back or fore gear, according to which is required. Having done this, any desired cutoff may be selected, and the throttle may be closed and reopened without resetting the gear, except as working conditions demand.

The results obtained with the British Caprotti valve gear provide much food for thought and, in my opinion, strengthen the case for working with wide open throttle and the shortest suitable cut-off. Reducing the admission period does not adversely affect the other valve events. Reducing the admission period with other valve gears also reduces the amount by which the port is open. But in the British-Caprotti gear the valve lift remains substantially the same at all cut-offs. Consequently on level track, it is possible to accelerate a. train using a cut-off as low as ?? per cent. This is what can be accomplished by a small quantity of steam admitted to the cylinders at maximum pressure to exert powerful thrust on the pistons at the commencement of the stroke. Another important factor. is that with this gear, exhaust is delayed to obtain the maximum work from the expanding steam.

When an engine is stationary, maximum power is exerted with the crank on top or bottom quarter, but at speed new factors come into operation. Then the steam exerts its force with the greatest effect in the rear part of the stroke, because as it nears mid-stroke, piston speed is reaching a maximum while steam pressure is falling to a minimum This, I think, explains the power and effectiveness of the British-Caprotti gear at such a low cut-off as 3 per cent. Steam passage into and out of the cylinders with comparative freedom and exerts its greatest

> pressure on the pistons, from the commencement the strobe, and continues to work up to the point of release.

**Wardale's response:** "Caprotti Performance" by P. Fraser adds nothing new. At best it might be taken as an indication that the Caprotti engine was better than a piston valve Class 5. This might be so, but we are concerned here not with 1930's piston valve design but state-of-the-art Porta type valves, which are a very different proposition. Contrast Fraser with C. J. Allen on 71000 in *British Pacific Locomotives:* "Some engine crews have been able to make nothing of the engine, and have lost time heavily ..." That's hardly scientific, it is true, but neither are the great majority of comments on the 5AT.

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**John Duncan's Comment 27:** *Excerpt from email from Angus Eickhoff published in Steam Railway issue No 276 Oct 2002 p.38 under the heading "David Wardale blueprint needs to be even more radical".*

> "Mr Wardale is rightly concerned about hammer-blow on a two-cylinder machine. Astonishing therefore that the engine has been drawn with ordinary Walschaerts valve gear, which will contribute considerably to the reciprocating masses. Surely a more sensible alternative would be to use British Caprotti valve gear, which has no reciprocating mass at all, and gave good results?
>
> Probably the strongest argument for rotary cam valve gear on such an experimental machine is that in order to change completely the characteristics of the valve events, all you have to do is insert a different set of cams.
>
> Certainly with regard to valve gear, Chapelon himself was very clear. "Poppet valves are necessary.... on locomotives with very high superheat to avoid the necessity for lubrication of admission ports of piston valves and thereby protect the oil from cracking effects and retain its value as a lubricant."
>
> Chapelon also outlined the problems with inertia and the amount of space taken up by modern piston valves. He pointed out that in order to achieve the same valve opening as a piston valve with a travel of 200mm (8in), a poppet valve only had to be lifted off its seat by a mere 30mm (1" approx), with a corresponding reduction in inertia forces."

**Wardale's response:** Quote from Angus Eickhoff (part relevant to valves only).

1. Walschaerts valve gear does not 'contribute considerably' to the reciprocating masses. Apart from the crosshead arm, union link, and reciprocating part of the combination lever, all very small components, no part of Walschaerts gear is considered when determining the engine's balancing. The above-mentioned items, with their bearings, contribute 4.9% of the total reciprocating masses to be balanced (FDC 8 (24) and (28)) - hardly 'considerable'.
2. "... such an experimental machine [as the 5AT]..." Is the 5AT experimental? I don't think that's likely to improve the possibility of funding. It is not experimental, and there will be no need to "change completely the characteristics of the valve events."

3. Cracking of oil is prevented by (a) delivering oil direct to the valve liners, (b) valve liner cooling and (c) preventing air from entering the steam chests and cylinders when drifting (drifting steam).
4. Piston valve inertia and high temperature steam have already been answered.
5. Space: there is adequate space for the 5AT steam chests and piston valves.

---

**John Duncan's Comment 28:**

"Moving on to another thorny issue, why has David chosen to use Walschaerts valve gear rather than one of the more modern poppet valve alternatives? Conventional gear links the operation of inlet and exhaust ports in a sub optimal way, while poppet valve gear enables the two events to be independently controlled.

While the Caprotti solution allows for efficient mechanical operation, electrical actuation would enable microprocessor control of the valve events, allowing the locomotive to operate at optimum efficiency over a wide range of conditions. Motorists will know that all modern cars have electronic engine control systems, while many readers will remember that electrically operated valve gear was successfully employed on a class of express Garratt locomotives between the wars.

Further the power required to operate poppet valve gear is considerably less than that needed to drive piston valves. Walschaerts gear is pretty to see and is reliable, but it really has no place on a 21st Century locomotive."

**Wardale's response:** Re quote from Bryan Attewell (part relevant to valves only).

1. Why is a poppet valve alternative 'more modern' than what is specified for the 5AT?
2. Linked valve events vs. independent ones: what does this actually mean for the desired end result, cylinder performance? Given the essential equivalence of 3450's and 71000's indicator diagrams, I would suggest the answer is very little.
3. "... electrical operation and microprocessor control ..." This is losing the plot again. For the purpose for which the 5AT has been proposed, it is to be kept as a classical steam locomotive as far as possible, which includes having the driver control it, which he is paid to do.
4. Power to drive the valves: already answered.
5. "... Walschaerts gear is pretty to see and is reliable..." Thank you.

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**Wardale's concluding paragraphs**

That answers all your and others' comments. It is a fairly definitive answer, and adds to, or supersedes, as the case may be, what may have been said previously on this subject. I think it gives a pretty robust case for the piston valve and valve gear design for the 5AT. In particular, your primary assertion, that only poppet valves arc suitable for high speed, is demonstrably wrong. Full stop.

To summarise, the only clear advantages of Caprotti valves appear to be:

1. Reduced cylinder oil consumption and
2. Larger valve openings for admission at short cut-offs.

The clear advantages of piston valves and Walschaerts gear, as specified for the 5AT, appear to be

1. Larger valve openings for admission at long to medium cut-offs,
2. Larger valve openings for exhaust at all cut-offs and
3. Aesthetically superior.

There are two main reasons why I do not agree in principle with your comments. Firstly, they are based on a comparison between BR (or 'first generation') piston valves and Walschaerts gear on the one hand, and Caprotti valves and gear on the other. What you have to say may or may not be valid for such a comparison. But, as should be clear, the piston valves and Walschaerts gear for the 5AT are on an altogether higher level than those of First Generation Steam in general, and BR locomotives in particular, which itself invalidates your arguments when applied to the 5AT design. Secondly, they are not supported by any engineering calculations. In general, comments and suggestions are all too often generalized, vague ('poppet valves are modern ...'; '2 cylinders are not suitable for high speed...'), not based on a proper engineering understanding, and unsupported by data. In view of this, it was agreed with Chris Newman some time ago that any comments and suggestions had to be supported by calculations to at least FDC level for them to be considered. Perhaps not surprisingly, the stream of suggestions dried up. I have taken some effort to counter your points in this case, but as with all other suggested alternatives to the 5AT specification, they must be supported by adequate engineering data, to FDC standard and specifically related to the 5AT, for a valid comparison to be made.

Well, despite all the evidence in favour of the current 5AT valve design, fixed ideas in the mind being what they are, I don't expect you to change your opinion. But I don't expect to hear any more on this subject either!

Best regards

D.W.