**The Balancing of the BR Class 9 2-10-0 Locomotives**
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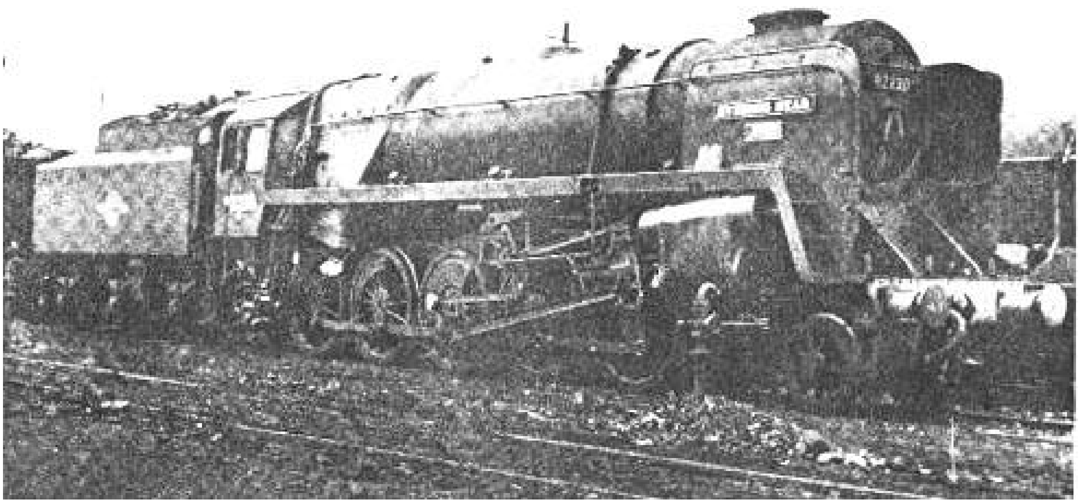
In his letter on page 190 of the Sept/Oct 1992 'Journal', Mr. Langridge, a much respected former chief of mine some 45 years ago asked about the balancing of these engines in view of their ability to run at 90 m.p.h., in spite of their relatively small wheels of 5ft diameter.

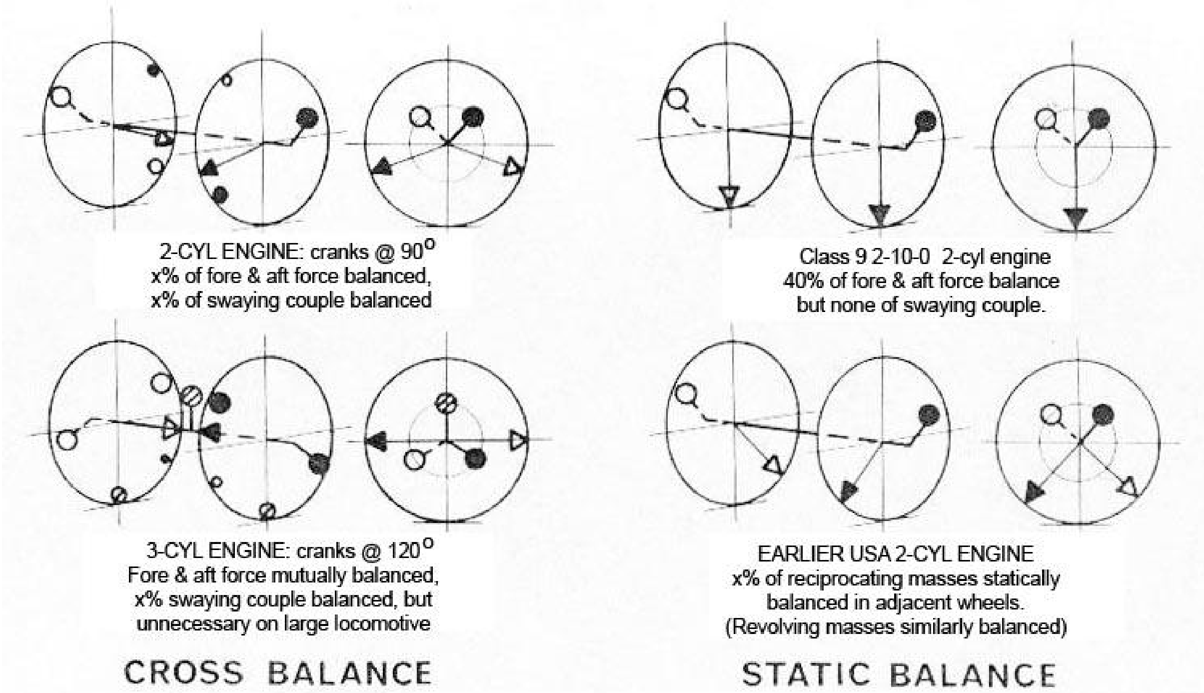
Whilst it does not seem to have been described in detail previously, the balancing of this class did differ from conventional British practice for 2-cylinder simple engines, which was to balance the same proportion of swaying couple as fore-and-aft disturbance arising from the reciprocating masses of the pistons and their rods, crossheads, etc., and a proportion of the connecting rods. On the Class 9 engines, none of the swaying was balanced, but 40% of the fore-and-aft disturbance was. The balance weights for reciprocating parts were therefore in phase on each wheel of a coupled axle and angled at 135$^o$ to each crankpin. This meant that hammerblow occurred simultaneously on each rail, the wheel blow being half the axle blow. BR Diagram SL/BR/1378 records equal axle hammerblow on all five coupled axles at 1.564 tons at 5 r.p.m. (53½ m.p.h.) and wheel hammerblows at 0.7189 tons. The static axle loads ranged from 15.15 to 15.90 tons over these axles.

The primary reason for adopting this different technique was to overcome a serious problem of inserting enough balance weights within the limited size of the wheels to provide the desired amount of balance for fore-and-aft disturbance. The severe restrictions of the British loading gauge in its bottom corners imposed great difficulties in keeping the big ends and other components within its confines, and so the width of balance weights had to be limited.



*Evening Star was not always kept in immaculate condition during its brief spell of service on B.R. as can be seen here at Cardiff Canton M.P.D. on 25th March 1961. The picture is Stephenson Photograph Collection Negative No 6281 - The late R. Cutler.*

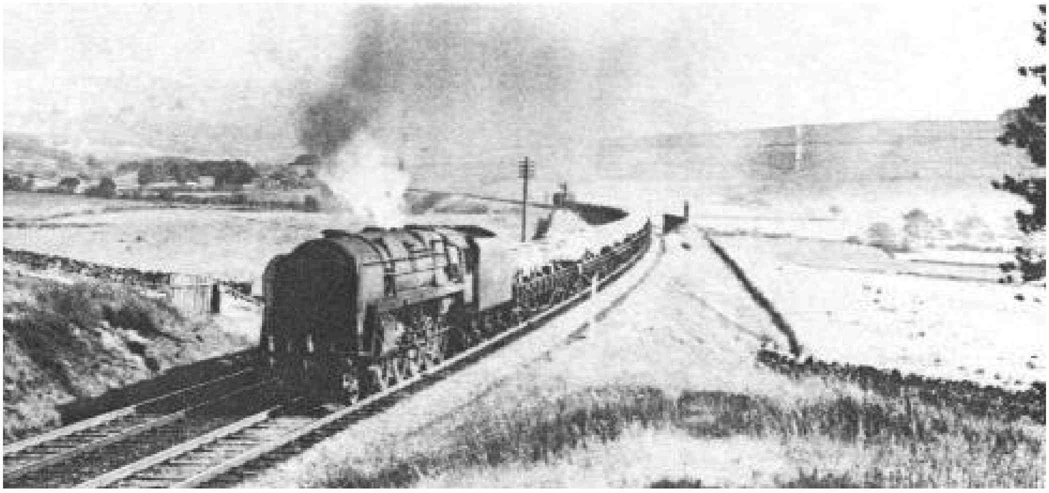
I rather doubt that this arrangement directly contributed to improved riding of the locomotive over what it would have been had 40% of the swaying couple been balanced in the usual way. However the rails no doubt appreciated the wheel hammerblows being considerably less, although the track and bridges received the same resultant axle (and locomotive) blow under either method. However the Class 9 produced this with simultaneous blows on each rail whereas conventional balancing gave large blows out of phase on each rail. This perhaps caused some torsional effects on bridges and other structures but probably had little significance in practice. The reduction in wheel blows was substantial, as wheel and axle blows for the BR 2-cylinder Class 7 4-6-2 engines, as built, were at 5 r.p.s. 2.12 and 2.55 tons respectively, i.e. the former was 83% of the latter as against only 50% on the Class 9. Total engine blow of each class was very similar as their cylinder sizes were identical as was the 40% fore-and-aft disturbance balance. The Class 9 had a slightly longer and heavier connecting rod.




The triangles indicate the position of the resultant balance weights for reciprocating masses, and account for the vertical hammerblows

The logic of the Class 9 balancing scheme was based on experience with the Bullied 3-cylinder Pacifics which had no balancing for reciprocating masses. Their fore-and-aft disturbance was effectively zero because the cranks were at 120° to each other. However the swaying couple was considerable because the outside cranks were at 120° to each other rather than only 90° on a 2-cylinder engine. This approximately compensated for the lighter reciprocating masses per cylinder on a 3-cylinder engine of comparable power.

Although swaying couple had in the past caused nosing on short lighter locomotives, it obviously did not have a significant effect on the longer and heavier ones, because of their much greater moment of inertia about a vertical axis and the lateral stability arising from the longer wheelbase.



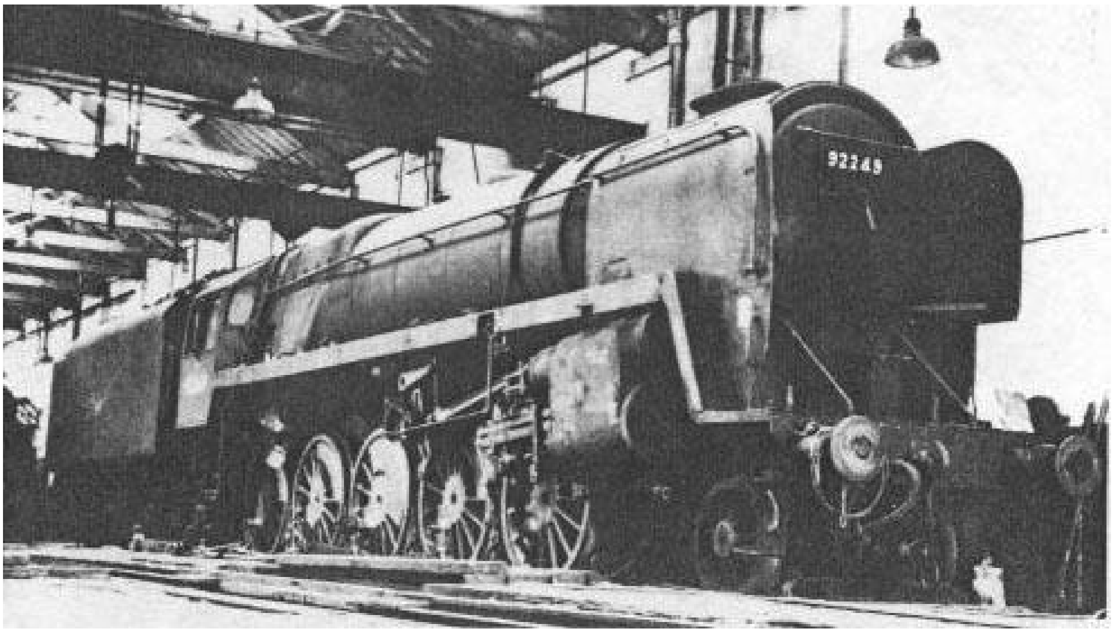
*9F 2-10-0 92115 on a Class C freight with a load of Ford cars at Greenholme on the climb to Shap Summit, banked at the rear by 4MT 2-6-4T 42095.*

As balancing of swaying couple proved unnecessary on a larger 3-cylinder engine, there seemed to be no need to do it on a larger 2-cylinder one. Experience with the Class 9 2-10-0s fully confirmed this.

Long standing British and Continental practice had been to use cross-balancing, which took account of the different vertical planes in which the various masses were situated. By this means, all revolving masses could be completely balanced. Reciprocating masses obviously could not be properly balanced by revolving balance weights in the wheels and if these were used to reduce a proportion of the horizontal disturbing forces, they automatically created a corresponding vertical force called hammerblow. In other words, the amount of reduction in horizontal disturbance was reflected into a vertical direction.

On the Class 9s, cross-balancing was not carried out in respect of the 40% of reciprocating masses, nor was the balance weight relating to each cylinder directly applied to the wheels on each side of the engine, as the Americans would normally have done. The balance weights were set in phase on each side. It will be realized that the total balance weights as seen on the wheels are largely concerned with balancing revolving masses such as crankpins and bosses, coupling rods and a proportion of the connecting rods.

It is interesting to review available hammerblow diagrams for some other large multi-cylindered locomotives. The LMS Pacifics had 50% of reciprocating parts balanced, but as the four cylinder arrangement was in balance fore-and-aft, the balancing applied only to the swaying couple. On the Princesses and Duchesses the wheel-blow at 6 r.p.s. was 1.89 tonnes diametrically opposed on each side of the engine, so that there was zero axle hammerblow and engine hammerblow. The Royal Scots as built and rebuilt, had wheel and axle hammerblows of 4.25 and 0.27 tons respectively for 66?×% balance and an engine blow of 0.56 tons, which obviously took into account the slidebar hammerblow. For the Rebuilt Patriots and Jubilees, the figures were 4.41, 0.33 and 0.88.




*92249 inside Carlisle Kingmoor repair shop on 9th Sept 1967*

The hammerblow diagrams seen for the LNER/ER Pacifics are rather perplexing and seem inconsistent between the classes and give rise to queries. It is too much for this article to embrace the complicated and diverse balancing arrangements on these 3-cylinder 4-6-2s and GWR 4-cylinder 4-6-0s, in which the inside cylinder(s) and outside ones were balanced in different ways and with varying distributions between the coupled wheels. The overall effect was to produce significant hammerblows at the wheels; in some cases virtually negating each other for the whole engine!

Bearing in mind the satisfactory experience with the unbalanced Bullied Pacifics on the S.R., it would appear that these companies were imposing unnecessary impacts on rails, tracks and structures with their larger multi-cylindered engines. It would seem that the valid need for reciprocating balance was to keep the fore-and-aft and swaying disturbances for the whole locomotive within acceptable limits, and to do this with a minimum of wheel hammerblows. If there was a good reason for doing otherwise, e.g. for the sake of the locomotive itself, perhaps someone could kindly elaborate?

It would be interesting to know how the Continentals dealt with this matter, especially the maestro, M. André Chapelon.

## North American Practice

For a long while, North American practice shunned the complication of cross-balancing, even for rotating masses. Balance weights were applied in the adjacent wheels to provide static balance so disregarding the different planes involved and their effect on dynamic balance.

Subsequently with the introduction of heavier and more powerful locomotives, various cases of kinked and damaged rails occurred although these were sometimes aggravated by the loss of lead from balance weights which were inadequately sealed. It came to be realized that procedures had been too casual and in 1931 the A.A.R. recommended cross-balancing for the main driving wheelset, but retained static balancing on the other wheels; furthermore that 31½% reciprocating balance be shared equally between all coupled wheels. In 1934 the recommended proportion was increased to 40%, but then new trouble arose from new 4-6-4s and 4-8-4s slipping at high speeds and kinking rails. A further review suggested that the main driving wheels should carry less reciprocating balance than the other coupled wheels because the former also sustained a vertical component of the piston thrust through the connecting rods. It was also recommended that the amount of reciprocating balance should be related to the total weight of the engine rather than be an arbitrary percentage of reciprocating masses. In addition it proposed the more exact treatment for assessing the proportion of con-rod weight as rotating by taking the centre of percussion into account. This somewhat reduced the amount previously assumed. For those interested, Ralph P. Jackson of the Baldwin Locomotive Company included a whole chapter on counter-balancing in his 1942 book 'The Steam Locomotive'.

## A Personal Note

The scheme described was evolved by Jim Jarvis when he was on a scholarship to the University of Illinois in 1951. He had previously presented, as a Graduate of the Institution of Locomotive Engineers, a paper on balancing to an informal meeting of the Institution at Derby in 1947, so he used that as a basis for the thesis that he was required to read to the class studying Mechanical Vibrations.

He had by that time read in American books about problems their railroads had experienced with damaged rails leading to the adoption of more sophisticated balancing techniques approaching those long-used widely in Europe as a matter of course. In thinking about these aspects, he began to query why British 2-cylinder engines should be partly balanced for swaying couple as well as fore-and-aft disturbance when experience with the considerable number of Bullied 3-cylinder Pacifics had shown that these locomotives rode well without any balancing whatsoever of their considerable swaying couple.

He forwarded this view to his chief at the Rugby Locomotive Testing Station, the late D.R. Carling, whence it seemed to have been passed via H.Q. at Marylebone, to the Brighton Drawing Office where by chance his brother Jim Jarvis[1] and his staff were finding difficulty in applying sufficient balance weights to the wheels of the Class 9 2-10-0s, then being designed, to balance them in the conventional way. The alternative method provided a solution to the problem.

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[1] R.G Jarvis was then Chief Technical Assistant to the C.M. & E.E. of Southern Region and in charge of Brighton, Eastleigh and Ashford drawing offices. For design matters, he was mainly responsible to the C.M. & E.E. H.Q. Marylebone.