Testing a Locomotive – *Syd Kennerly*

Syd passed this article on to me for possible use in the Newsletter. I am not sure of the original source but it is interesting stuff – Mike Brown

How the efficiency of a Modern Railway Engine is Proved

A DESIGNER'S work on a locomotive does not end when the product of his brain begins work on the track. It is not enough that the engine hauls its load within the scheduled time.

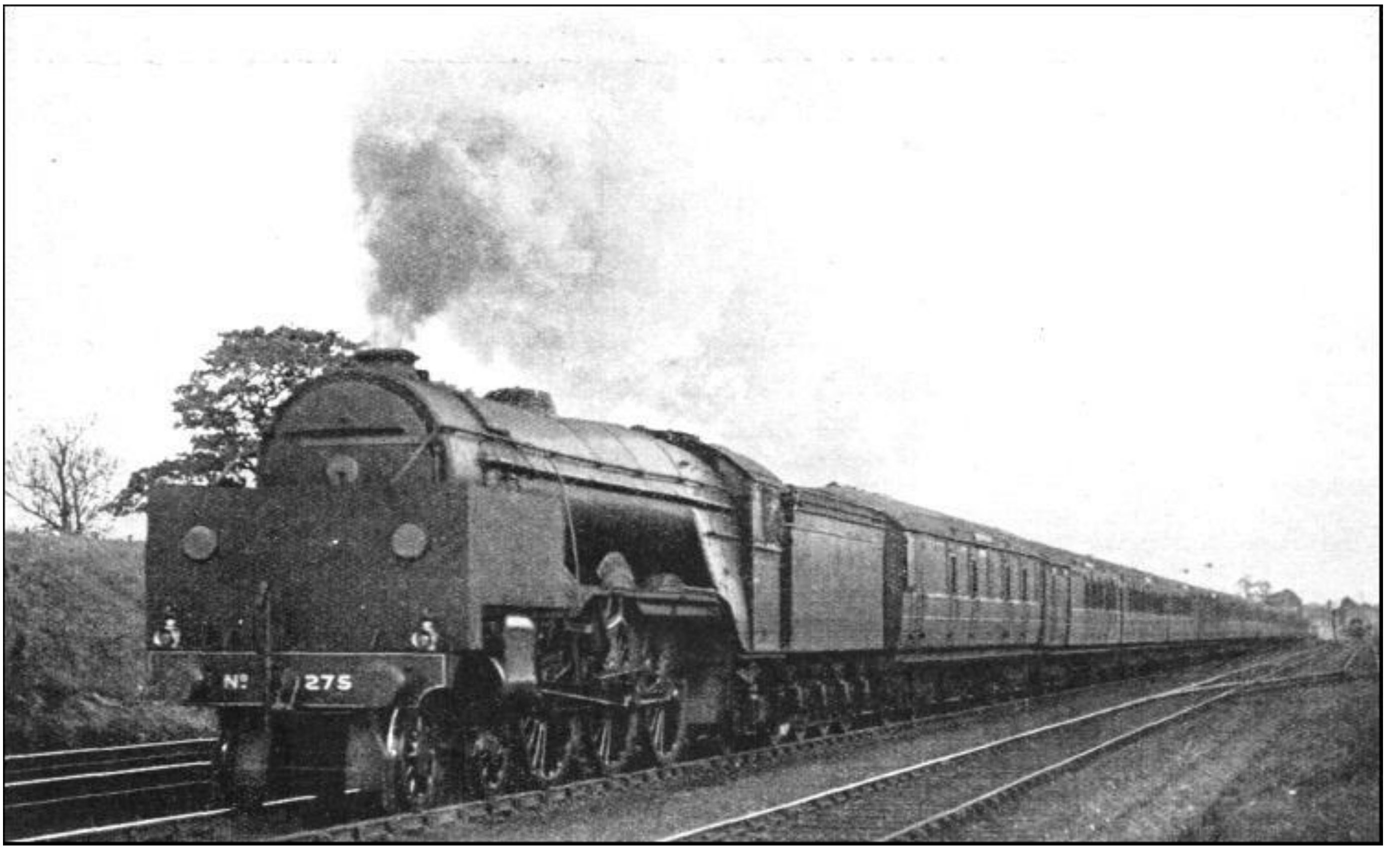
Once on the track it must be tested to ascertain the horse-power that the engine is developing in relation to the amount of fuel that it burns; unless this is done the engine may prove to be uneconomical in its work. This test of horse-power requires measurement of the pull exerted by the engine on its train during the course of the journey.

But the horse-power exerted by the locomotive on the train takes no account of the power that it utilizes in moving itself and its tender; therefore means must be devised of measuring the total horse-power exerted by the locomotive while in motion. To do this, there must be an examination of what is going on inside the engine cylinders. This examination also makes it possible to determine if, at all speeds from the lowest to the highest, the expansion of the steam in the cylinders is going on efficiently.

Another important line of investigation concerns the boiler; the designer will want to know that the combustion of the fuel on the fire-grate is thorough and complete, and that no valuable sources of heat and energy are being thrown out of the chimney. This calls for an analysis of the gases in the smoke-box, and it is necessary for the analysis to be carried out while the locomotive is in motion. All these tests are usually conducted at the same time.

Round the front and two sides of the smoke-box of an engine undergoing its tests is a shelter, generally made of sheet steel, and containing two windows in front. This is to house two observers, who, well muffled up, half scorched by the heat of the smoke-box, and half frozen by the draughts behind them, "indicate" the engine during the course of the test journey. Their temporary home is known as an "indicating shelter."

The indicator itself consists of a small vertical cylinder with a rotating motion, worked by a connexion off the motion of the engine. Every time the driving wheels of the engine rotate, the indicator makes one complete forward turn and one backward turn, so that it is in rapid motion, forwards and backwards alternately, all the time the engine is running. An opening is made in the front cover of one of the cylinders, and from this a small tube is led to the indicator. In this steam-tube, therefore, the steam is at a pressure exactly corresponding with the pressure in the cylinder between the cylinder-end and the piston.



THE INDICATING SHELTER - Attached to the front of a "Pacific" locomotive undergoing tests. Members of the engineering staff ride in this compartment for the purpose of taking indicator diagrams of the expansion of the steam in the cylinders and collecting various smoke-box data.

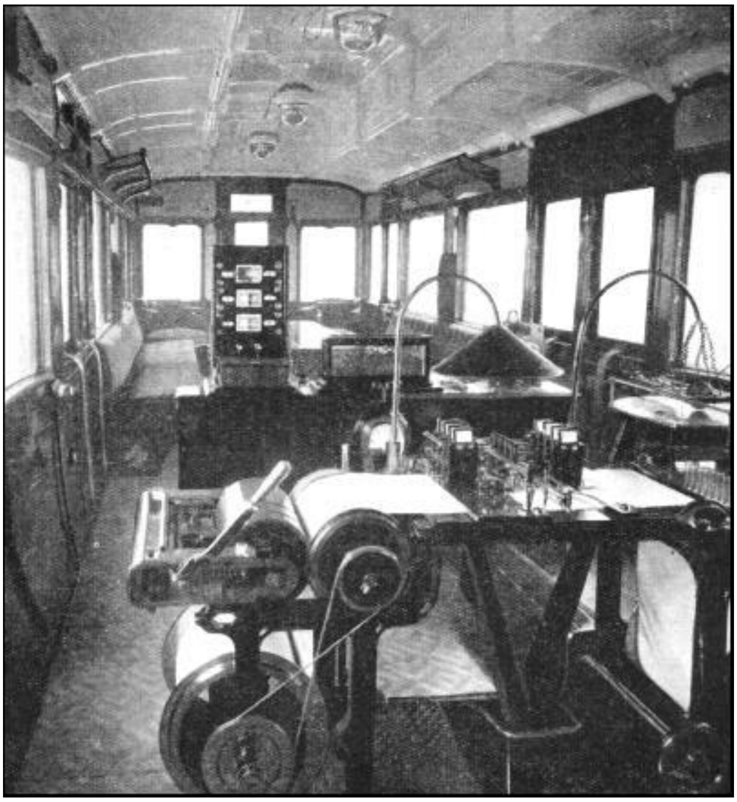
As the piston moves away from the cylinder-end, the pressure is at first roughly equal to the boiler-pressure, while live steam is still being admitted ; then comes the moment of "cut-off," after which the steam does the remainder of its work by expansion, and the pressure rapidly drops until the end of the piston-stroke. But at this point it may tend to rise again, owing to what is called "back-pressure"—that is, pressure on the other side of the piston, as the expanded steam from the last previous stroke is being pushed out of the cylinder up into the chimney, and the final stage is reached when the piston "cushions" that steam up against the opposite cylinder-end. In designing and setting modern valve-motions, the aim is to use the expansive properties of the steam to the maximum, and to reduce the back-pressure or cushioning to a minimum, as more efficient working will result from the realization of both aims.

It is of this process of expansion that the indicator diagram gives an exact picture. At the selected moment the observer in the shelter opens a cock in the small steam tube; the pressure in the tube actuates a small pen, which rises and falls according to the actual pressure in that end of the cylinder; the pen makes a line on the rotating cylinder of the indicator, to which a sheet of paper has been fixed. It is shaped like a boot. The top horizontal part of the "upper" shows the pressure as steam is admitted up to the point of "cut-off" ; the sloping front of the boot, where it would be laced, down to the toe-cap, represents the expansion from the cut-off to the end of the forward stroke ; and the underside of the boot, from sole to heel, represents the pressure in the same end of the cylinder on the return stroke of the piston, as the expanded steam is being "exhausted" to the chimney. A "fat" diagram is sought; thin diagrams often mean inefficiency, especially if, near the end of the stroke, the return, or exhaust, line crosses above the line representing the final stage of the expansion; this shows that excessive backpressure is taking place.

From the indicator diagrams, which are taken at a large number of selected points during the test journey, it is possible not only to watch the process of expansion in the engine cylinders at all speeds, but also to make an approximate calculation of the total horse-power which is being developed by the locomotive. A certain proportion of this—and the proportion so expended must obviously be kept to the lowest possible percentage—is used in propelling itself and hauling its tender.

The remainder, which represents the value of the locomotive as an operating unit, is available for the haulage of its train, and this has now to be measured. The difference between the two figures will show how much of its power the engine has expended in moving itself.

This brings us to a special vehicle, known as a "dynamometer car," which is used for measuring the pull exerted by the locomotive on its train. The dynamometer car is marshalled in the train next to the engine tender, and at its leading or business end the coupling hook of the car forms part of a drawbar of special design. This drawbar is attached to a powerful system of springs under the car, against which it pulls, and which reduce its forward and backward movements within narrow limits. By careful design and calibration the springs are so arranged that the movement of the drawbar is exactly proportionate to the pull that the engine exerts on it.



Recording instruments of various kinds are carried inside the dynamometer car. In the foreground of this picture is the machine for recording the drawbar pull of the locomotive, which is marked on the roll by one of the nine pens in the centre of the table. In the background is seen the apparatus for analysing the gases in the smoke-box of the engine.

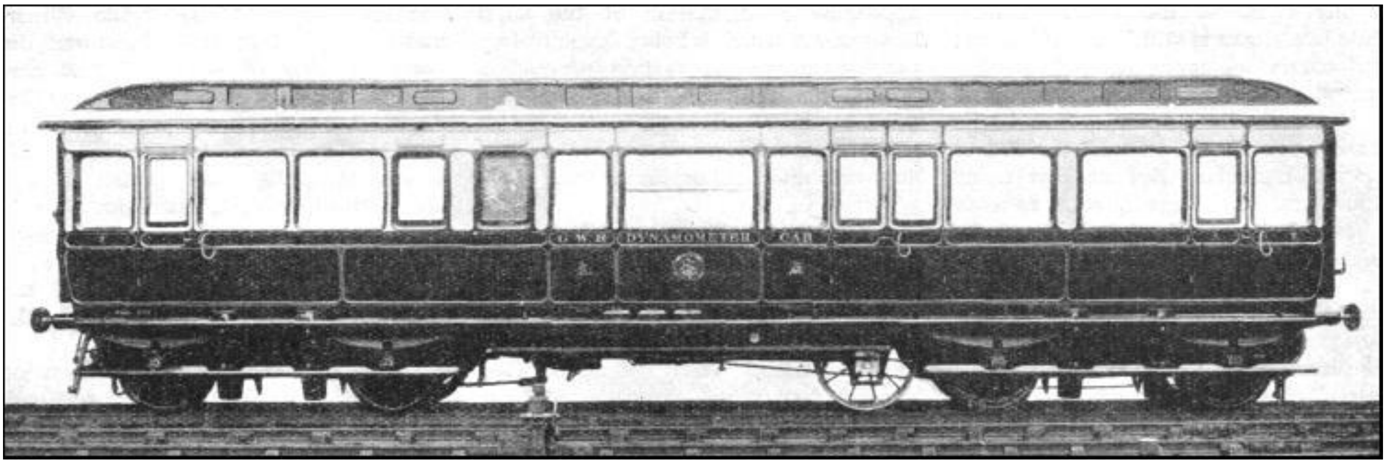
Inside the car, the visitor's attention is first attracted by a table at one end, over which is passing a wide band of paper, winding from a large roll on one side of the table to another roll on the other side. The paper is being kept slowly in motion by clockwork or other suitable method. Poised above the table are a number of pens, each one of which has some special function to perform in marking the roll during the course of the test journey. The most important of these pens is the one which, by a system of levers, is directly connected with the drawbar described in the last paragraph. This pen is in constant contact with the roll and inscribes on it a complete picture of the engine's pull on the train from the start of the journey to the finish.

The biggest effort of all occurs at the moment of starting. Cut-off in the cylinders is advanced to the maximum extent, so that the full working pressure of the boiler is forcing the pistons from one end of the cylinders almost to the other. This is necessary because the "static friction" of the axle-boxes of every coach throughout the train, between the axles and the journals which bear on them, must be overcome before motion can begin. With a big modern express engine and a train of 500 or 600 tons behind the tender, this initial pull may rise to twelve fifteen, or even seventeen tons, and the drawbar pen makes a corresponding sudden upward movement across the width of the roll. Immediately, however, the pull drops off, leaving this starting effort like a spear-point on the diagram. The engine is gradually "notched up," as cut-off is reduced, and the expansive properties of the steam are brought into play, while the drawbar pen drops until it is seen that, for a speed of, say, 70 miles per hour on the level with a 500-ton train, a pull of two to three tons on the drawbar suffices to overcome all resistances to the movement of such a load at such a speed along rails.

The most important line along the dynamometer car diagram thus begins with a sharp peak, and then drops to a wavy horizontal line, rising when the train is running uphill and when greater horse-power is demanded, and falling on the downhill stages, where, if the gradient be steep enough, the train, may actually be pushing the engine. All the other pens are performing their various functions at the same time. There is telephonic and bell communication between the observers in the indicating shelter on the front of the engine and the dynamometer car staff, and also between the car and the engine footplate. A mark is made on the record at the precise point where each indicator diagram is taken; another mark is made at every point where the driver of the engine varies the opening of his regulator (or throttle), and the percentage of his cylinder cut-off. The exact passing of stations and mile posts is also marked on the roll for distance-checking purposes.

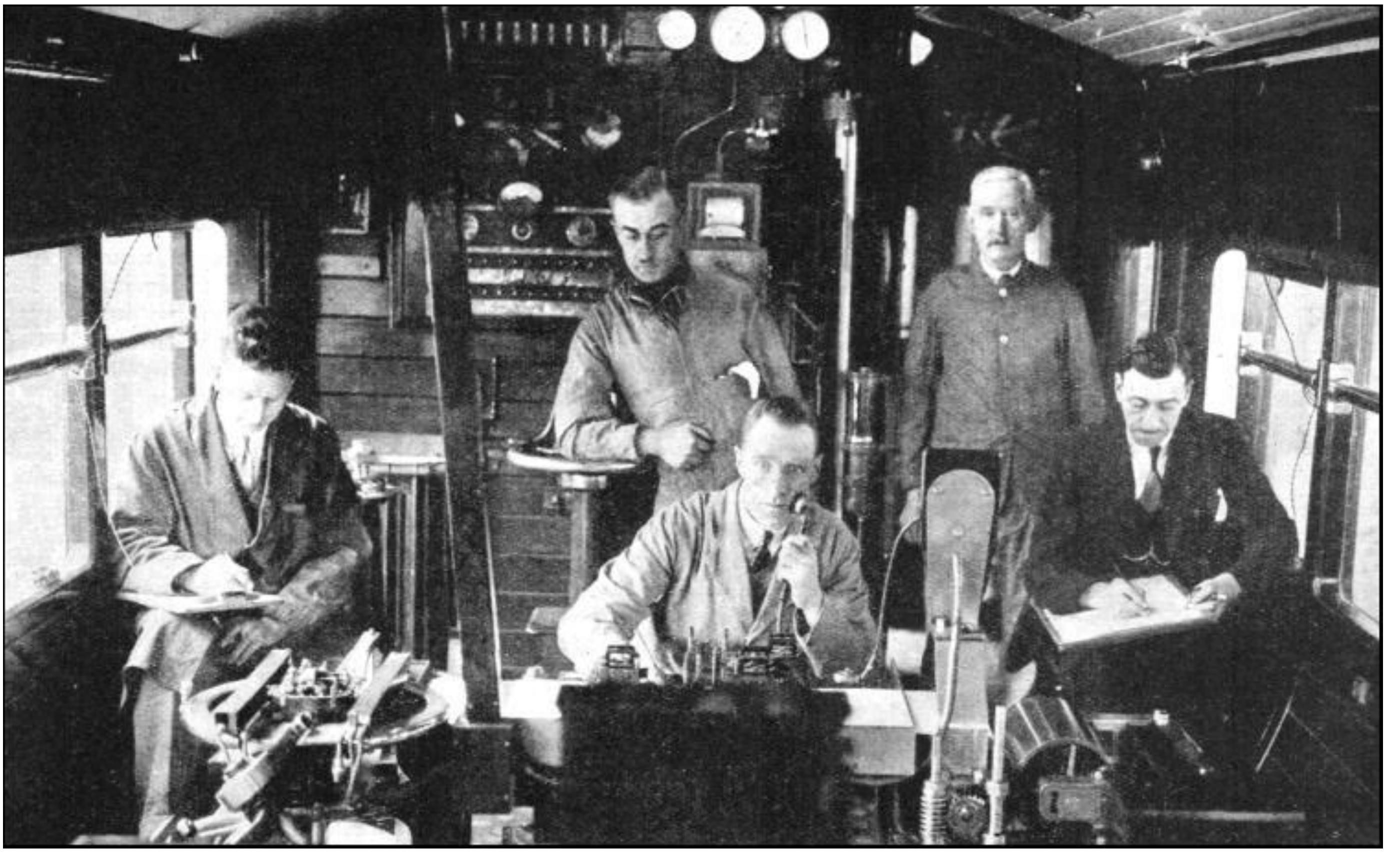
Inside the dynamometer car there is another important apparatus, which is directly connected by tubing with the interior of the engine smoke-box. At any desired point on the journey a sample of the gases in the smoke-box is in this way conveyed directly into the car, where this apparatus receives it, and automatically resolves it into its component parts. That is to say, a series of analyses is made, at all speeds, of the residual products of the combustion of the fuel. It is possible in this way to check whether or not the engine is throwing out of the chimney fuel constituents. Instead of being thrown to waste they might be employed for raising steam. The maximum possible proportion of the calorific value of the fuel must be used in the conversion of the water into steam; if this is not done the locomotive is inefficient.

Among other details connected with a test journey of this description, it is important to keep a close check on the quantity of coal and water used. The coal is weighed as it is deposited in the tender prior to starting, and the residue is weighed again at the end of the journey; the difference, with the addition of what was used for "lighting up," gives the total consumption on the route. The water in the tender tank and in the boiler is measured before the start and after the termination of the run. The supplies that were picked up from track-troughs during the course of the journey must be added to the amount of water measured at the end of the run. From these details the rate of evaporation of the water in the boiler can be calculated, and can be proportioned to the rate of consumption of the fuel on the fire-grate.



A DYNAMOMETER CAR - Attached between the locomotive and the train, is used for making tests under working conditions. This coach is 48 ft. 5 in. long and weighs 27 tons 3 cwt. In the car a moving roll of paper, on which the principal records are made, is operated by clockwork and the extra wheel shown. This can be raised or lowered from the underside of the carriage to the rail as required, and is used to record on the roll the speed at which the train is travelling. The wheel is fitted with a hardened steel tyre, ground to such a diameter that it makes exactly 440 revolutions for each mile run.

Busy though the observers on the engine and in the dynamometer car have been during the course of the test journey, they are busier still when the run is ended, for all the diagrams have now to be worked out, and the mass of figures that has been accumulated requires detailed and critical analysis. The results are of the greatest value, and fully justify the considerable expense of maintaining the equipment and providing the staff of nine or ten skilled engineers that is needed to conduct such tests as these. As a result of studying the indicator diagrams, for example, the authorities may decide to make alterations in the valve-setting ; the analysis of the smoke-box gases may suggest modifications in the design of the fire-grate, firebox, boiler, barrel, or smoke-box ; and similarly, from the dynamometer record, decisions may be reached that will result in changes in design, either in the engine under test, or succeeding engines of the same class, or the next type to be designed.



MEN OF A DYNAMOMETER CAR - Attached to the "Flying Scotsman" express on the London and North Eastern Railway. The engineer at the central desk is in telephonic communication with a colleague on the locomotive.

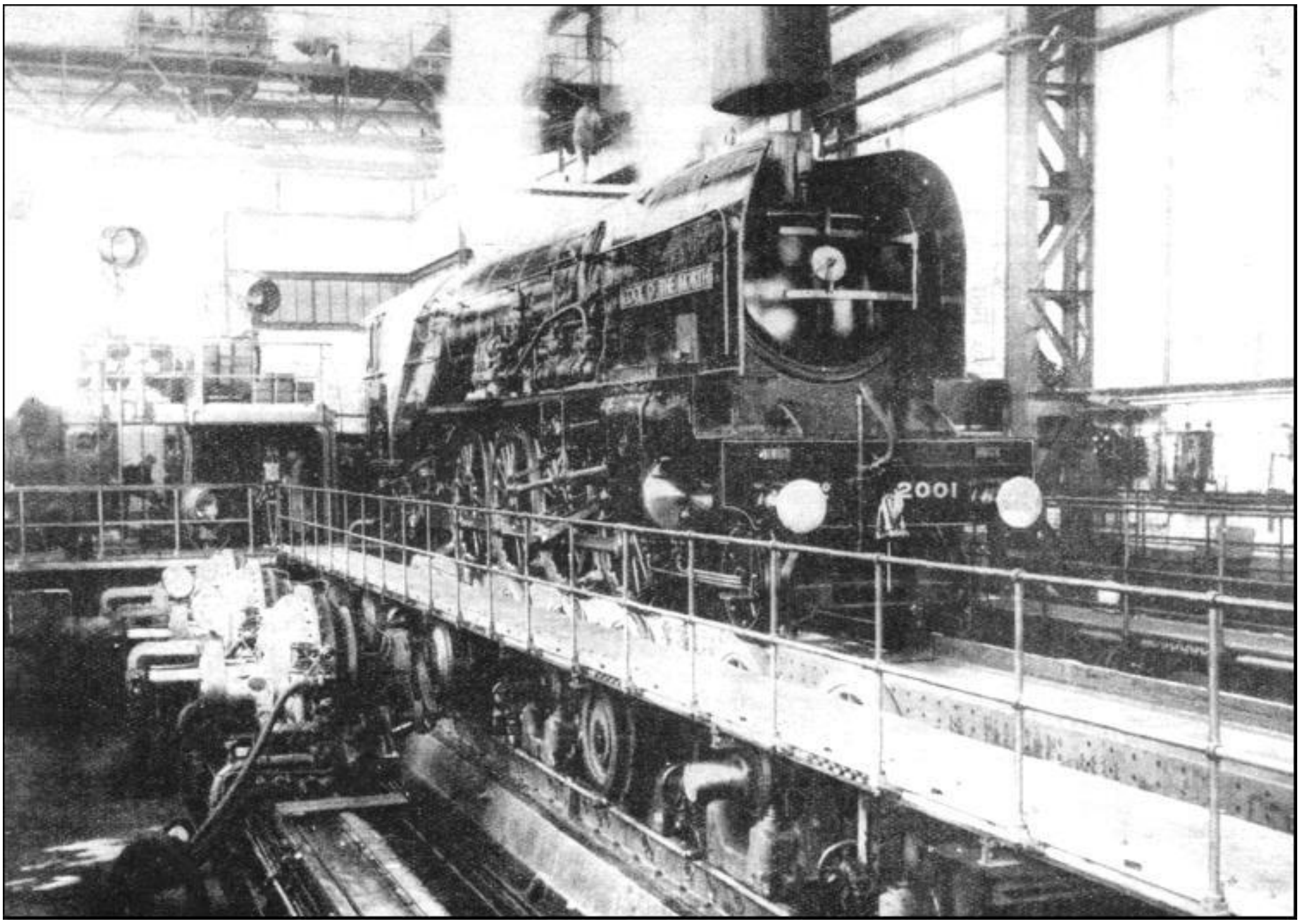
Testing of this description is also used to precede time-table changes, as it is necessary to prove, if accelerations of service are planned, that they will not lead to excessive coal consumption and inefficient working of the engines concerned.

There is another way of testing a locomotive, which reproduces all the conditions of running, in the matter of load and speed, but without requiring that the engine shall be taken for a test journey over a stretch of line with the dynamometer car.

This method is independent of weather variations, especially of the effect of side-winds, which dissipate power through increased friction, and of mist or rain, which makes the rails greasy. Every different type of locomotive can be tested in conditions which are not merely uniform, but which cannot vary. The disadvantage of this method is that it requires the erection of a costly testing-plant. Such plants are in use in the United States, Germany, and France, but the only one of its kind in Great Britain is at the Swindon Works of the Great Western Railway, and this can test only up to 500 horsepower, which falls far short of modern requirements.

One of the most up-to-date plants is at Vitry, near Paris, to which the London & North Eastern locomotive "Cock o' the North" was sent in December, 1934, in order that exhaustive tests might be made. Along the floor of the testing-plant there are arranged a series of rollers, the position of which can be adjusted until each of the wheels of the engine under test is resting exactly on the centre of a roller. Each of the rollers beneath the driving-wheels of the engine drives a Froude hydraulic brake; in its turn the shaft of the brake drives a hydraulic pump, and any increase of the engine's speed also increases the rate of water supply to the brake, so increasing the braking force, and keeping constant the rate of rotation of the engine's driving wheels.

The drawbar or coupling of the engine is then attached to a hydraulic dynamometer, which is anchored to a vertical girder set in concrete. The engine, held thus securely in position, is put in steam, started, and worked up to the equivalent of a high speed, travelling, theoretically, some hundreds of miles.



ON TEST. The "Cock o' the North," the great L.N.E.R. 2-8-2 locomotive, in the testing shop at Vitry, France. The engine, without the tender, is held securely at the rear, with the wheels resting on rollers. Steam is raised in the boiler, and all quantities of water and fuel used are carefully measured. The locomotive regulator is opened and the wheels cause the supporting rollers to revolve. The rollers are coupled to paddle wheels inside the water drums shown at the left of the picture. The churning action of the paddles absorbs the power of the engine and provides a load which can be varied and measured at will.

Standing on its rollers, roaring as though travelling speedily on a track, with the driving-wheels driving the rollers as hard as they can go, and working against the hydraulic pressure in the Froude brakes, the standing engine presents an odd appearance. In this way it is possible to work the engine at an even speed for hour after hour, without any variation of method due to up-gradients and down-gradients, curves and slowings, signals and permanent way checks, or wind and weather. The pull of the engine on the dynamometer is being registered, as it would in a dynamometer car, but far more accurate estimates of the engine's efficiency are being obtained than would ever be possible in an ordinary test run along the line.

At its best, the steam locomotive is, thermally, one of the least efficient of steam engines. Out of every 100 units of heat developed by the consumption of the fuel on the fire-grate, not more than six or seven, in normal running, are turned into useful work. Yet there are many reasons why it is difficult to alter this state of affairs for the better.

When the steam has done its work in the cylinders, and is thrown out of the chimney, a good deal of power goes with it, as is evident from the noise that is made by the exhaust, especially when the engine is starting. Owing to the relative shortness of the boiler a good deal of heat also passes up the chimney to waste. But both conditions are the product of the narrow limitations of height, width, and weight within which the locomotive must be built, in order to pass over railway tracks, alongside platforms, and through tunnels and bridges.

Throwing the exhaust up the chimney provides the necessary draught for the fire, and the terminal pressure of the steam before exhausting must be sufficiently high, or there will not be sufficient draught to enable the boiler to steam correctly.

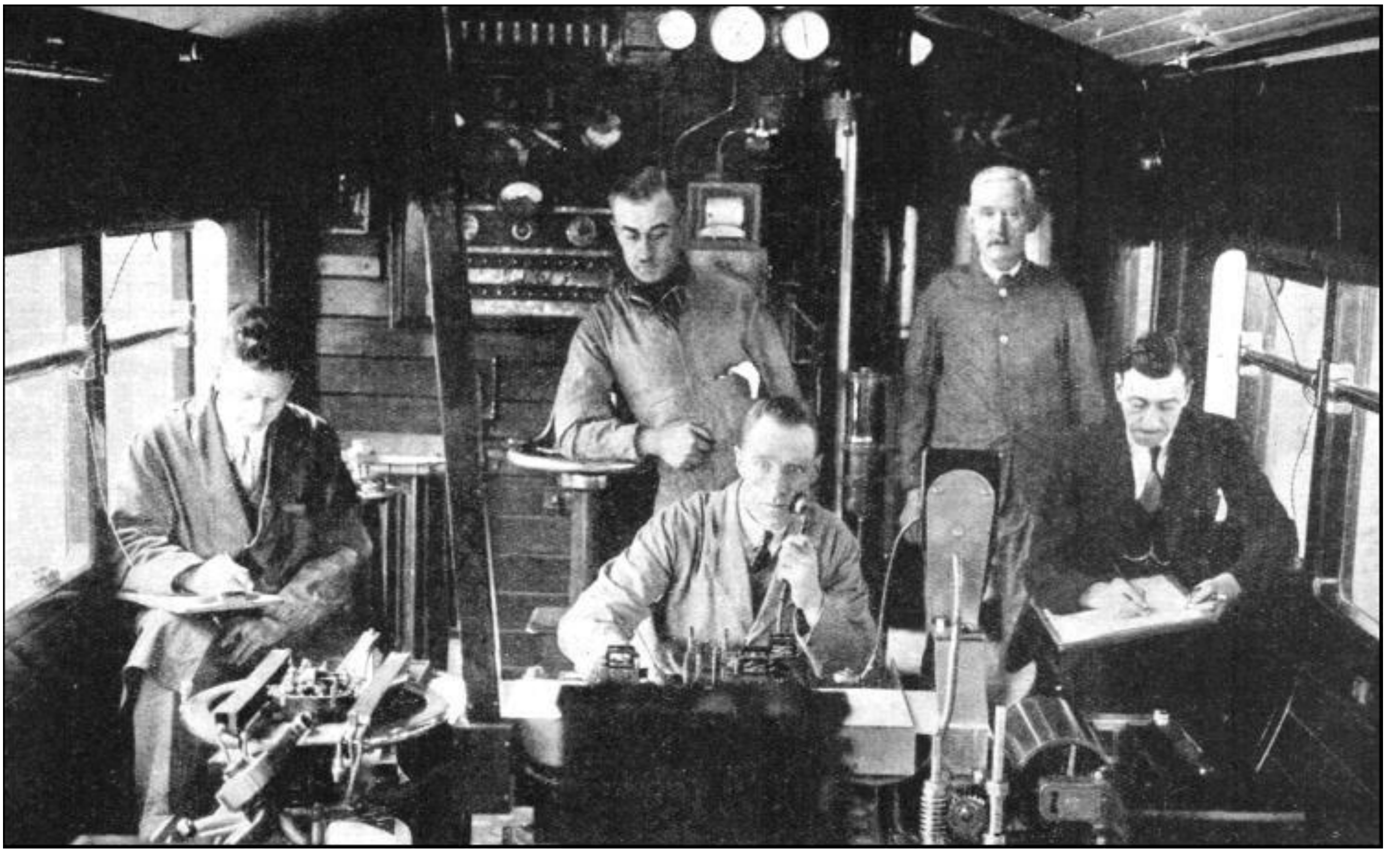
Undue lengthening of the boiler barrel, to utilize a larger proportion of the heat of the fire for steam-raising purposes, would increase the weight and length of the locomotive, and defeat its own object.

Attempts have been made to trap the escaping power and heat, by substituting turbine drive for reciprocating motion, by condensing the exhaust steam and by substituting some form of forced draught, but without any marked success, because of these constructional limitations in locomotive building.

For the wide range of duties that it has to perform, the steam locomotive, despite its low overall thermal efficiency, is still the most suitable type of machine for its work. Efforts are being made constantly to increase the efficiency figure; from 7-1/2 to 10 per cent, for example, would alone add one-third to the efficiency of the locomotive. And in securing greater efficiency, it is the various methods of locomotive testing described on this page that play the most important part in the investigation.

There are other important tests that precede the building of a locomotive. Every steel plate or rolled section used in its construction was inspected and tested by representatives of the railway company at the rolling mill where the steel was produced. Steel forgings and castings were subjected to a similarly careful scrutiny, as well as the copper from which the internal firebox has been shaped, and the tubes connecting the firebox with the smoke-box.

All these various parts have been manufactured to rigid specifications which have been drawn up as the result of experience, most of them the work of the British Engineering Standards Association. A large corps of inspecting engineers is maintained by each railway company, and travels the country visiting, for inspection and testing purposes, the works of firms that supply railway materials. Each railway also maintains its own laboratories, staffed by expert chemists and metallurgists, who have much testing to do in connexion



MEN OF A DYNAMOMETER CAR, attached to the "Flying Scotsman" express on the London and North Eastern Railway. The engineer at the central desk is in telephonic communication with a colleague on the locomotive.

Another aspect of locomotive testing, however, relates not so much to efficiency in design and performance, as to the matter of safety. For example, the axles of a modern express locomotive are usually made hollow. These are specially bored to allow the interior to be microscopically examined so that any flaws or defects may at once be apparent. The danger of a broken axle may thus be averted by periodical inspections during the running life of the locomotive.

Other tests are carried out from time to time, particularly with regard to boilers. These are inspected at specified intervals of time, so that any signs of corrosion may be detected.

A boiler is subjected to rigorous tests before being fitted to a locomotive. The boiler, after it leaves the shop where it is built, is tested under a hydraulic pressure at a figure which is well above its working pressure. In this test the boiler is filled with water. A powerful pump then forces in more water until the pressure gauge registers the required figure.

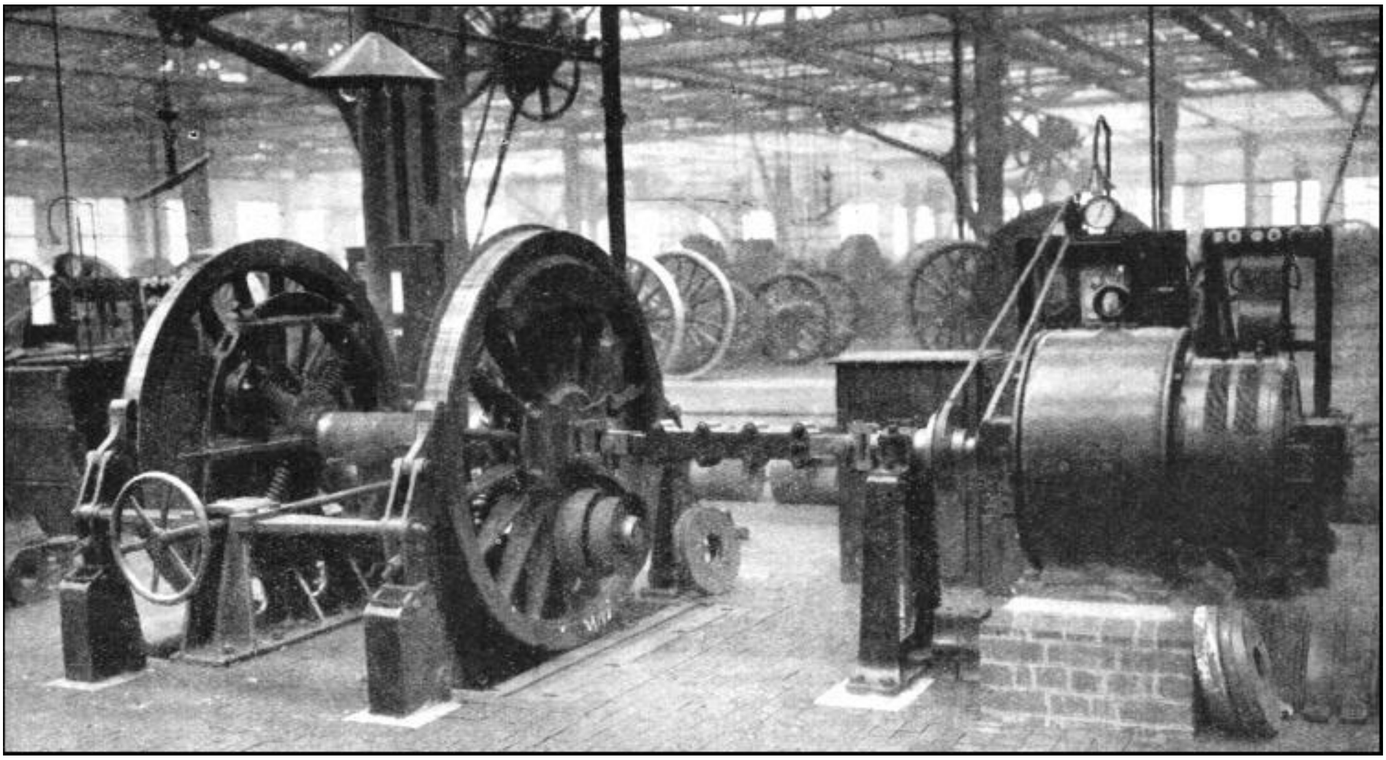
This, though severe, is not regarded as sufficient for complete safety, and the boiler is subjected to a further test, steam being raised until the working pressure of the boiler is attained. At this figure the safety valves are set to blow off, but the engineer's test proves that all joints in the boiler shell and between the tubes and the smoke-box and firebox tube-plates are properly steam-tight.

A large number of tests are carried out, also, during the building of a locomotive, to ensure both efficiency and safety in working. An example of this is the elaborate testing of locomotive driving wheels before they are fitted to the engine frames. Driving wheels are operated by connecting rods which in their turn are worked by reciprocating motion.

These reciprocating parts are very heavy, and "balance weights," as they are known, are attached near to the rims of the wheels. These weights are placed opposite to the crank-pins through which the power of the cylinders is transmitted to the wheels. It is obvious that a balance as nearly perfect as possible must be achieved if steady running without undue vibration is to be attained. To this end it is necessary to mount the driving axles, complete with their wheels, in a special machine in which they are revolved at a speed equivalent to well over sixty miles an hour on the track. Any unsteadiness of the wheels due to lack of "balance" is corrected by adjusting the weights. These balance weights consist of boxes of hollow cast iron, or assembled from steel plates, which are filled with lead, so that the amount of metal they contain can be added to or taken from at will. The wheels are finally run up to a very high speed, and if they undergo this test successfully they are passed for service on the locomotives for which they have been made.

There is yet another aspect of locomotive testing which is of vital importance. This is the distribution of locomotive weight over each of its wheels. This is adjusted by running the locomotive into a special shed in which the track is divided up into a series of short weigh-bridges. Each of the engine wheels rests over one of these weigh-bridges and the downward pressure is measured on a dial ; thus the engineer in charge can see at a glance the weight, in tons and fractions of a ton, which rests on each wheel. Should any alteration be necessary to the distribution of the engine's weight, the springs are adjusted carefully, so that both the driving and carrying wheels bear their due proportion of weight, evenly distributed on both sides of the engine.

The locomotive undergoes a series of tests throughout its construction. Tests are also taken during the running life of the engine to ensure that it shall be safe and efficient.



WHEEL BALANCING, an important part of a locomotive's testing which is carried out during construction. This machine, at Swindon locomotive works, is used to ensure that all engine driving wheels shall be capable of spinning without undue vibration, at a speed equivalent to over sixty miles an hour on the track.