ON RECENT BRAKE EXPERIMENTS UPON THE LYONS RAILWAY.

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I. PARTICULARS OF APPARATUS.

The Paris and Lyons Railway has lately experimented on two trains, one fitted with the Westinghouse brake, and one with the Smith Vacuum brake. Both trains were alike, and were composed as follows :—

Vehicle.	Axles.	Load per axle.	Total load.
1 engine, 4 axles (in working order)	{ 2 driving axles, together 2 loose axles do.	lbs. 55,125 44,100	99,225
1 tender, 3 axles (in working order)	{ 1st axle, with brake 2nd axle, without brake..... 3rd axle, with brake	25,357 17,640 25,357	68,354
25 carriages (empty) 3 axles	{ 1st axle, with brake 2nd axle, without brake 3rd axle, with brake	7,276 6,394 7,276	20,946
Same carriages (loaded) 3 axles	{ 1st axle, with brake 2nd axle, without brake..... 3rd axle, with brake	8,676 7,594 8,676	24,946

The engine is not fitted with any brake, except the "Le Chatelier" counterpressure apparatus. This apparatus,* as improved by the chief engineer, M. Marié, has worked excellently for fifteen years, in daily use, both in all stops at stations, and also on long inclines. Some remarks will be made hereafter on the power of the counterpressure apparatus compared with a brake on the driving wheels.

* See Proceedings 1870, p. 21.

Each carriage had only two axles fitted with brakes, the middle axle being left free; the fear of the complication arising from a six-wheel brake was the reason of this: but, in order to have power enough, a great brake-block pressure was provided. The following Table shows the brake-block pressure on every axle of the train. The pressure in the brake cylinder is here supposed to be 37 lbs. per square inch; and the vacuum in the "Hardy" sack to be 16 inches of mercury. These pressures must be considered as an average of the ordinary pressures in practice.

	Air Pressure, or Vacuum.	Pressure on the outside blocks.	Pressure on the inside blocks.	Total brake-block pressure per axle.	Load on rail for each braked axle.	Ratio of Brake-block pressure to load.
WESTINGHOUSE.	lbs. per sq. in.	lbs.	lbs.	lbs.	lbs.	Per cent.
Tender (1st and 3rd axle)	37	6,666	10,016	16,682	25,357	66
Empty carriage (1st and 3rd axle braked)	37	4,191	6,303	10,494	7,276	144
	37	4,191	6,303	10,494	8,676	121
VACUUM.	Inches vacuum.					
Tender (1st and 3rd axle)	16	15,020	9,874	24,894	25,357	98
Empty carriage (1st and 3rd axle braked)	16	8,342	5,045	13,387	7,276	184
	16	8,342	5,045	13,387	8,676	154

The pressures were not large enough to skid the wheels at high speeds, but at low speeds the wheels were skidded, especially with empty carriages. This latter is no real disadvantage, because in ordinary stops the driver can moderate the brake power. Mr. Westinghouse however, in order to avoid skidding under any circumstances, fitted, as a trial, twelve carriages with reducing valves, operated by the friction of the brake blocks. The arrangement of these was the same as is given in Captain Galton's paper (Figs. 1-3, Plates 19 and 20).

It will be seen that, in the case of the Westinghouse brake, the pressure on the outside blocks (or those furthest from the centre of the vehicle) is less than on the inside blocks, which arrangement has the disadvantage of creating a strain on the horn plates, equal to the difference of these two pressures; but has, on the other hand, the following advantage. When the brake is applied to the whole train, each carriage is subject to a strain, created by inertia, equal to the

mass of the carriage, multiplied by the rate of retardation of the train. This strain equals, on an average, about $\frac{1}{10}$ of the weight of the carriage; it acts as a forward push applied to the centre of gravity of the carriage, and changes the distribution of the weight on the axles, the front axle becoming more loaded than usual, and the rear axle less. This is an important matter, because the springs of the carriages are sometimes damaged by the action of this extra load on the front axle. Mr. Westinghouse has therefore arranged his brake gear in such a way as to create a vertical force, counteracting partially this extra load, by giving more pressure on the inside blocks than on the outside ones. These pressures being different, the frictional resistances are different also, and the difference forms a vertical force acting upwards on the springs of the front axle, thereby balancing so far the action of inertia.

In the case of the Vacuum brake gear the pressure on the outside blocks is greater than on the inside ones, which causes a reverse action, so as to add to the extra load created by inertia upon the front axle. From this it follows that the compression of the front springs is somewhat greater in the case of the Vacuum than of the Westinghouse brake. In the Westinghouse brake gear this difference of pressures is equal to $6303 - 4191 = 2112$ lbs. for each axle; and the difference of frictional resistances is equal to $\frac{2112}{5} = 422$ lbs. (with a coefficient of friction of $\cdot 20$). In the Vacuum brake gear the difference of pressures is equal to $8342 - 5045 = 3297$ lbs.; the difference of resistances is therefore equal to $\frac{3297}{5} = 659$ lbs. Thus with the Westinghouse brake there is a counteracting force, as described, of 420 lbs.; whilst with the Vacuum brake there is an augmenting force of 660 lbs. From this cause the front springs are more loaded with the Vacuum brake than with the Westinghouse; and this strain is still greater towards the end of the stop, because the friction increases considerably at that moment, as may be seen in the friction diagrams of the Brighton experiments. The practical result of this during the trials was that in the Westinghouse train only one front spring was flattened down, while in the Vacuum train all were. The author does not understand the object of the latter type of brake gear, which is generally applied with the Smith brake, and is also extensively used by the Great Northern Railway in England.

It is impossible to avoid entirely the above-mentioned strain on the horn plates ; and in addition, the horizontal force retarding the train must produce another strain on the horn plates, which is equal to $\frac{10,494}{5} = 2099$ lbs. per axle for the Westinghouse brake. Thus with this brake the horn plates of the front axle have to support two strains in opposite directions, one equal to the difference of the brake-block pressures, or 2112 lbs., and one equal to the retarding force, or 2099 lbs. ; the resultant strain is therefore only $2112 - 2099 = 13$ lbs. But on the horn plates of the rear axle the forces act in the same direction, and therefore the total strain is equal to $2112 + 2099 = 4211$ lbs. From this point of view it would be better to have the same brake-block pressures on both sides of the wheel, so that the strain on the horn plates should be only 2099 lbs. at each end of the carriage ; the advantage of unequal pressures, as above described, would then be lost, but still the author would prefer this arrangement.

The stroke of the piston, both in the air cylinders and in the Hardy sacks, was calculated so as to have a theoretical clearance of $\frac{3}{4}$ inch between the blocks and the wheels, when the brakes were off. In the trials, the distance between each block and its wheel was $\frac{3}{8}$ inch when the brakes were off ; the difference, $\frac{3}{8}$ inch, was allowed for the bending and springing of the brake gear.

II. PRACTICAL WORKING OF THE TWO BRAKES.

Trains fitted with a Westinghouse and with a Vacuum brake have been running for two months from Paris to Montereau (49 miles) and back, and from Paris to Corbeil (20 miles) and back. The Westinghouse brake has worked very well when there has been no leakage in the pipes, but it is necessary to watch all the apparatus with the greatest attention ; sometimes one or two of the triple valves get out of order, and disturb the action of the brake, causing very severe shocks to the couplings, especially with trains of twenty-four carriages. The Vacuum train has also given good results, but the couplings are often damaged ; the operation of putting the couplings together is much more difficult than with the Westinghouse brake. With both brakes the passengers generally feel no shock,

provided the driver releases the brake a few yards before the end of the stop. The practical trial of both these trains has as yet been too short for giving any definite conclusion.

III. EXPERIMENTS OF THE 1ST AND 2ND APRIL.

The London Brighton and South Coast Railway, as represented by their general manager, Mr. Knight, and locomotive superintendent, Mr. Stroudley, sent over to the Lyons Railway the experimental van already used during Captain Douglas Galton's experiments at Brighton and York. The author takes this opportunity of thanking those gentlemen, and also Captain Galton, Mr. Westinghouse, and Mr. Kapteyn, of Paris, for their assistance in these experiments. A description of the apparatus has already been given in Captain Galton's papers on the subject. In the present experiments two diagrams only were taken for each stop; first, the diagram from the speed indicator, giving the square of the speed of the train at each point of the distance run; second, the diagram giving the brake-block pressure on the front axle of the van. This axle had been fitted with a Westinghouse brake and with a Vacuum brake, which could be used independently. In Captain Galton's experiments the abscissæ were made proportional to the time, the recording cylinders being connected with a water clock, and so turned round with a uniform speed. In the Lyons experiments, the abscissæ were made proportional to the distance run by the train; for this purpose the recording cylinders were connected with the rear axle of the van; that axle had no brake, and therefore gave a distance exactly proportional to the distance run by the train. When the train was run without brakes being applied, this connection between the recording cylinders and the rear axle was broken; when the driver applied the brake, the connection was immediately and automatically established by means of friction gearing, actuated by electricity. The brake-block pressure is exactly proportional to the air pressure in the brake cylinder, or to the vacuum in the Hardy sack. On the diagrams, Plate 18, are two scales, adapted for measuring the air pressure and the vacuum from the diagram of the brake-block pressures. The lines marked W denote the Westinghouse brake, and the lines marked V the Vacuum. The full lines show

the speeds, and the dotted lines give the air pressure in the brake cylinder in lbs. per square inch, or the vacuum in the Hardy sack in inches of mercury. It will be seen that in Captain Galton's diagrams the lines of speed are convex towards the base line, while in these they are concave; the reason of this is the difference already explained between the abscissæ used in each case.

On 1st April experiments were made with the Vacuum brake. From Paris to Montargis (73 miles) the train was composed of engine, tender, ordinary van, experimental van, twenty-two carriages. From Montargis to Paris the train was much shorter, comprising engine, tender, ordinary van, experimental van, six carriages. On 2nd April the same experiments were made with the Westinghouse brake, and with the same number of vehicles. A great many diagrams were taken, from which five are chosen, representing the average of all the cases. By the aid of those five diagrams, Figs. 1-5, Plate 18, the results may now be described.

Fig. 1 represents two stops with twenty-four carriages (including the two vans), one stop with the Westinghouse, the other with the Vacuum brake. The weights of the trains were as follows :—

	Weight on unbraked wheels.	Weight on braked wheels.
Engine	lbs. 99,225	lbs.
Tender	17,640	50,714
Carriages and van, empty	147,062	334,696
Experimental van, loaded	10,000	10,400
Total.....	273,927	395,810

Total weight of the train, 669,737 lbs.; proportion on braked wheels, 59 per cent.

In order to be exact there ought to be added to the total weight of the train the weight of all the unbraked wheels, because the brake is obliged to destroy the rotating momentum of those wheels. But, as this error is very small, and the same for both brakes, it has not

been taken into consideration in the calculations. The results of Fig. 1 are therefore as follows :—

Brake.	Speed of Train.	Length of Stop.	Duration of Stop.	Gradient.	State of Rail.
	Miles per Hour.	Yards.	Seconds.		
Westinghouse	37	217	20½	{ Rising 1 in 200 }	Dry.
Vacuum	35	280	24½	Level	Rather wet.

The diagram shows the variation of the air pressure in the brake cylinder, and of the vacuum in the Hardy sack. The full pressure was almost instantaneously applied with the Westinghouse brake; its variation shows the action of the regulating valve in the van. The vacuum increases slowly, and reaches 13½ inches at the end of the stop; in the rear of the train the vacuum was no doubt created more slowly still, but no experiments with recording apparatus were made to ascertain this point.

This trial was the most unfavourable for the Vacuum brake, the number of carriages being large and the speed small.

Figs. 2 and 3 show a few stops with the return train of eight carriages (including the two vans).

The weights of the train were as follows :—

	Weight on Unbraked Wheels.	Weight on Braked Wheels.
	lbs.	lbs.
Engine	99,225	
Tender	17,640	50,714
Seven Carriages empty	44,758	101,864
Experimental Van loaded	10,000	10,400
	171,623	162,978

Total weight of the train, 334,601 lbs.; proportion on braked wheels, 49 per cent.

The particulars of the stops were as follows:—

Brake.	Speed.	Length of Stop.	Duration of Stop.	Gradient.	State of Rail.
	Miles per Hour.	Yards.	Seconds.		
Westinghouse, Fig. 2	63½	550	32	{ Falling } { 1 in 200 }	Dry.
Vacuum, Fig. 2 ...	60½	570	37	Do.	Quite wet.
Westinghouse, Fig. 3	37	203	16½	{ Falling } { 1 in 1000 }	Dry.
Vacuum, Fig. 3 ...	37	213	19½	Do.	Quite wet.

The two first stops (Fig. 2) were made with the aid of the counterpressure of the engine; the two last (Fig. 3) were made without counterpressure. The line C of Fig. 3 shows a stop made with counterpressure alone.

As may be seen, the results are not very different, the trains having very few carriages.

Fig. 4 shows a stop obtained with the Westinghouse brake, worked from the rear van of the train. The following are the particulars:—

Speed, 40 miles per hour.

Length of stop, 248 yards.

Time, not observed.

Gradient, level.

Rail, dry.

The train had exactly the same composition as that in the experiments with eight vehicles; the regulator of the engine was kept full open until the train had come to rest.

Fig. 5 shows a slip experiment with the Westinghouse brake. The part of the train which was slipped was composed of the experimental van and six carriages. The weights were as follows:—

	Weight on Unbraked Wheels.	Weight on Braked Wheels.
	lbs.	lbs.
Experimental Van loaded ...	10,000	10,400
Six carriages empty	38,364	87,312
Total.....	48,364	97,712

Total weight of the train, 146,076 lbs.; proportion on braked wheels, 67 per cent.

The following are the particulars of the stop, which was a very good one:—

Speed, 41 miles per hour.

Length of stop, 150 yards.

Duration of stop, $12\frac{1}{2}$ seconds.

Gradient, level.

Rail, dry.

In this stop, as in the last, the recording instruments were started by the air pressure in the brake cylinder of the van, instead of being started by electricity as before. There was in consequence a slight loss of time, especially in the stop from the rear van, Fig. 4.

IV. COMPARISON OF THE RETARDING FORCES IN DIFFERENT STOPS.

It is easy to compare stops with each other, although the speed, the gradient, and the proportion of weight on braked wheels be different in each. This can be done by calculating the retarding forces of the brake for each stop.

If we call S the speed in miles per hour, l the length of the stop in yards, and W the weight of the train, then the retarding force F is given by the formula:—

$$\frac{F}{W} = 0.011 \times \frac{S^2}{l}.*$$

The diagrams give with precision the values of S and l in each stop; hence it is easy to calculate the retarding force in each case. On the diagrams, the ordinates are proportional to the square of the

* Let s be the speed of the train in yards per second, t the number of seconds of the stop, and l the length of the stop in yards. Then, if we suppose the retardation k to be constant during the stop, $s = kt$. Also $l = \frac{1}{2}kt^2$; hence $l = \frac{1}{2}k \frac{s^2}{k^2} = \frac{1}{2} \frac{s^2}{k}$; thus, if we take the value of k from this formula, we have $k = \frac{s^2}{2l}$.

Now let g be the acceleration of gravity in yards per second; let F be the retarding force of the brake in the whole train, and let W be the total weight of the train. Then, because forces are proportional to their accelerations, we have:—

$$\frac{F}{W} = \frac{k}{g} = \frac{s^2}{2lg} = 0.011 \times \frac{S^2}{l}.$$

speed, and the abscissæ proportional to the length of stop; thus the average retarding force is proportional to the inclination of the straight line drawn between the extremities of the speed curve, while the exact retarding force at each point of the diagram is given by the inclination of the tangent to the curve at that point. We can now compare stops made at different speeds.

To compare stops made on different gradients, we must add the gradient to $\frac{F}{W}$, with the sign + if it is falling, and with the sign - if it is rising. We will call $\frac{F'}{W}$ this corrected retarding force.

To compare stops in which the percentage of weight on braked wheels is different, let A be that percentage. If we multiply $\frac{F'}{W}$ by $\frac{100}{A}$, we have a number $\frac{F''}{W}$, which would be the retarding force for a train stopped on a level line with the whole weight of the train braked.

If we calculate the values of $\frac{F''}{W}$ for all the stops, the numbers obtained compare exactly the powers of the brakes, whatever may be the circumstances of the stop. The following Table gives this comparison for the present diagrams:—

(See Plate 18.)]	Speed S.	Length l.	$\frac{F}{W}$	Gradient.	$\frac{F'}{W}$	Percentage of Weight on Braked Wheels.	$\frac{F''}{W}$ Power of the Brake.
Westinghouse, alone: 24 car- riages, Fig. 1	37	217	0.075	{ rising } 1 in 200	0.070	59	0.119
Vacuum, alone: 24 carriages, Fig. 1	35	280	0.057	level	0.057	59	0.096
Westinghouse, alone: Slip experiment, Fig. 5	41	150	0.130	level	0.130	67	0.200
Westinghouse, alone: Brake from rear van, Fig. 4	40	248	0.080	level	0.080	49	0.160
Westinghouse, alone: 8 car- riages, Fig. 3	37	203	0.085	{ falling } 1 in 1000	0.086	49	0.170
Vacuum, alone: 8 carriages, Fig. 3	37	213	0.080	{ falling } 1 in 1000	0.081	49	0.160
Counterpressure alone: 8 car- riages, Fig. 3	35	583	0.024	level	0.024	16	0.150

The stops in Fig. 2 have not been worked out because they were made with the brake and the counterpressure together.

The retarding force $\frac{F}{W}$ ought to be diminished by the ordinary resistances of the train, that is to say, by 0·003 to 0·008. This makes but a small difference when the proportion of braked weight is large; but in the last stop, with counterpressure alone, this correction gives to $\frac{F''}{W}$ a value 0·125 instead of 0·150.

V. GENERAL CONCLUSIONS.

We have seen that the value of $\frac{F''}{W}$ is the best comparison for the power of the brakes in all cases. Now with the Westinghouse brake $\frac{F''}{W}$ is generally between 0·120 and 0·200, while with the Vacuum brake $\frac{F''}{W}$ is generally between 0·100 and 0·160. This shows a slight advantage for the Westinghouse brake, but it must be remarked that the rail was better during the trial of the Westinghouse than of the Vacuum brake. We have also seen that the value of $\frac{F''}{W}$ for the counterpressure is 0·125, while the average of the Westinghouse trials gives 0·160, with a brake-block pressure of about 140 per cent. of the weight on the braked wheels. Thus the counterpressure on the driving wheels is as powerful as a Westinghouse brake which has a pressure of $140 \times \frac{125}{160} = 109$ per cent. of the weight on those wheels. It may be suggested that in a quick stop the time occupied in reversing the steam on the engine must practically diminish the power of the counterpressure; this is true, but on the other hand the brake-block pressure on the driving wheels with the Westinghouse brake is generally less than 109 per cent., and often less than 80 per cent. Thus the counterpressure is as powerful as the Westinghouse brakes generally in use on the driving wheels. On the Lyons railway the drivers have been accustomed to the counterpressure for fifteen years; hence, whatever may be the final choice of brake, the Company will put no brake on the driving wheels.

The diagrams show that the Westinghouse brake comes on almost instantly over the whole train; it is not the same with the Vacuum brake. There the brake goes on first upon the front carriages, and

the buffers are consequently compressed; afterwards the carriages all become braked, and the buffers return to their first position, but not without oscillations which are serious, both for the passengers and for the couplings themselves. In the Westinghouse brake this action is much slighter.

In all the trials the wheels skidded only at a very low speed; hence the regulating valves did not show any great advantage in the length of the stop. They save the tyres by preventing the wheels from skidding, and they save also the springs of the carriages by diminishing the shock felt at the last moment of a stop. Though a very ingenious improvement, yet, if the driver can really graduate the strength of the brake, it may be doubtful whether they are necessary in continuous brakes; thus one more complication may perhaps be avoided.

The Lyons Railway had never previously had an accident caused by the breaking of draw-bars in a passenger train, but several were broken in the trains fitted with the Westinghouse and Vacuum brakes. Thus, if there has been no such breaking of draw-bars in past times, yet these are almost sure to occur frequently with the use of continuous brakes: and as there are on the railway several very steep gradients, it would seem that a non-automatic brake would on this line at least be dangerous, unless, to avoid accidents, the ordinary hand brakes are still kept in use on the trains.

The arrangements of the Westinghouse brake are certainly rather complicated, especially the air pump and the triple valves. As regards the pump the author thinks that it would be difficult to make an air pump more simple and at the same time able to satisfy all conditions. And as regards the triple valve, he thinks it is impossible to simplify it without losing one of the two following advantages—the quickness of application of the brake, or its graduation in the stops. It might however be rendered less delicate by making it larger and stronger. All the other parts of the brake are quite satisfactory.

All the parts of the Vacuum brake are very simple and strong, but the leather of the Hardy sack seems to be a bad material for practical work. Some arrangement of metallic pistons and cylinders

would seem preferable, but practice alone can decide this question. The arrangement of the brake gear is not quite satisfactory, but it would be easy to improve it.

The above opinions must be taken as those of the author alone, and as requiring to be checked by longer experience. Both brakes will be tried on long inclines, and a uniform speed maintained with them if possible. Until these trials have taken place, no decisive opinion can be given by the railway company.

BRAKE EXPERIMENTS, LYONS RAILWAY.

Plate 18.

Miles per hour.

Fig 2. Eight Carriages, WITH Counterpressure.

Fig 4. Westinghouse Brake worked from Rear Van.

Fig 5. Slip Stop, Westinghouse Brake.

References { W = Westinghouse Brake V = Vacuum Brake.
— Speed --- Pressure or Vacuum.

Miles per hour.

Fig 3. Eight Carriages, WITHOUT Counterpressure.

Fig 1. Twenty-four Carriages.