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" BRAKES FOR MODERN EXPRESS PASSENGER TRAINS,"

BY

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To describe, with anything like completeness, even one type of brake apparatus used on modern express passenger trains would obviously be impossible within the limits of a paper like the present. It appeared to the Author, however, that it might be interesting, and perhaps not entirely unprofitable, to the members of this Society, to hear what are the problems involved in the design of such a brake and to learn something of the various methods which have been adopted of overcoming the difficulties. He has, therefore, avoided any attempts at detailed description of more or less complicated pieces of apparatus, and has simply endeavoured to present to his hearers in broad but clear outline, the most essential features of a successful brake for this class of train.

Let us consider what such a brake should be capable of doing. In the first place it should be able to stop the train without uncomfortable shocks or oscillations and without putting any undue stress upon the draw gear, and it should be possible to apply it with full power without risk of sliding any of the wheels and so producing flat places on the tyres and consequent noisy and rough riding of the vehicles.

In the second place it should be at least sufficiently powerful to enable the train to run at the full speed necessary to keep time without any risk of over-running the home signal should a distant signal be sighted at danger. In foggy weather this means that it must be possible for the driver to run at full speed right up to the distant signal.

In the third place it should be capable of being released quickly in order that as little time as possible may be lost in making slacks. It is often necessary for an express train to reduce speed considerably at a junction or sharp curve, and if the brake cannot be applied with something approaching full power without bringing the train to a stand, and if, when the junction is passed, the brake cannot be quickly released and steam again put on, it is obvious that much time will be lost in making the slack, which must be subsequently made up in running, thus unduly taxing the powers of the locomotive. Here again, power is a desideratum in order that the full speed may be maintained to a point as near the junction or curve as possible, so that time is not wasted in reducing speed.

In the fourth place a satisfactory brake should have a graduated release : that is, it should be possible to release the brake partially and to any desired extent. This is especially useful in running down a long bank. A brake which, if released at all, must be taken off altogether is, far from being an ideal instrument for controlling a train under such circumstances. When the brake has to be released completely and re-applied every time it is desirable to ease it off, a great deal of skill is necessary to maintain anything like a regular speed, and there is some risk, in unskilful hands, of an undesirably high speed being attained before the brake is re-applied.

In the fifth place it should be capable of being applied by the guard as well as the driver. It should also be automatic, that is, it should apply itself in case of the train breaking away, or in case of any vital injury to its mechanism. These features are required by law of any brake in use on British railways.

Finally, it should be capable of stopping the train quickly in case of emergency. It is obvious that, other things being equal, a brake which will, if required, stop a train under certain circumstances in, say, 400 yards, is superior to one which, under the same circumstances, cannot stop it in less than 500 yards. An ideal brake would, of course, be capable of exerting, instantly and throughout the whole stop, the maximum retarding force which the adhesion of the wheels to the rails would allow, which is, in ordinary circumstances, a force equal to about 20 per cent. of the weight of the train, and would stop it in 200 yards on the level from 60 miles per hour. This is, however, impossible in practice for various reasons.

To stop a train in emergency so as to avoid an accident, although it is certainly one of the functions of a brake, is one which is very seldom required. No minimum distance can be definitely laid down in which the train must be stopped in these cases. An unexpected obstruction may be sighted at any distance, and when going at any speed, and, in the great majority of such instances, it will either be the case that any brake which is in use would stop the train in time, or that no brake could possibly be made which would do so. Moreover, such emergencies are, in themselves, rare.

In the opinion of the Author, the only practical criterion of power in a brake is that laid down above, that it must be capable of stopping the train between the distant and home signals when running at the maximum rate of speed. Any capacity the brake may have of stopping the train in a shorter distance than this, is all to the good, but it may be possible to pay too high a price for it.

Such then are the functions which a satisfactory brake for a modern express passenger train should be capable of performing, viz., stopping the train without shock or damage, enabling the driver to run up to a distant signal in foggy weather at full speed with the certainty of being able to stop at the home signal should the " distant " be " on," enabling a " slack " to be made with minimum loss of time, enabling the train to be easily controlled down a long bank, being capable of being applied by the guard, applying itself in case of a breakaway or accident, and stopping the train as quickly as possible in case of emergency.

It should, however, not only be capable of performing these functions, but should do so with certainty, and at as low a cost as possible in initial outlay and expenses of working and maintenance, and with a minimum of complication. In other words, it should be reliable, cheap, economical and simple.

In the early days of continuous brakes, experiments were made with various sources of power, but, at the present time, two sources only are employed, compressed air and the pressure of the atmosphere ; the latter being rendered operative by the creation of a vacuum.

The best known and most widely used compressed air brake is that manufactured by the " Westinghouse Brake Company." The " New York " air brake is, however, used to some extent in America, and the " Knorr " air brake in Germany. The principle of all these brakes is the same, they differ only in minor details.

There is a greater variety of brakes employing atmospheric pressure, commonly known as " Vacuum " brakes, but here again they differ only in details, the principle being the same. The best known type of Vacuum Brake is that manufactured by the "Vacuum Brake Company."

In compressed air brakes a steam pump is provided on the engine by means of which air is compressed into a large reservoir, known as the " MAIN RESERVOIR," to a pressure of about 90 lbs. per square inch. From this reservoir it is admitted, by means of a valve actuated by the driver, at a reduced pressure, usually about 70 lbs. per square inch, to a pipe running the whole length of the train, and known as the " TRAIN PIPE." On each vehicle there is a small reservoir, known as an " AUXILIARY RESERVOIR," a cylinder, the piston of which is connected, through a suitable system of rods and levers, with the brake blocks ; and a valve, known as the " TRIPLE VALVE," in connection with the train pipe, reservoir and brake cylinder.

When air is admitted to the train pipe it so actuates the triple valve on each vehicle that air can flow from the train pipe to the auxiliary reservoirs, the brake cylinders being at the same time put into communication with the atmosphere. There is thus on each vehicle a store of compressed air at about 70 lbs. per square inch (apart from that contained in the train pipe) and, there being no pressure in the brake cylinders, the brakes are off. This condition is maintained as long as the train is running, the pressure in the train pipe being maintained by allowing sufficient air to be admitted to it from the main reservoir to make up for any lost by leakage, while that in the main reservoir is maintained by means of the pump.

When it is desired to apply the brakes, the driver so manipulates his valve as to cut off all communication between the main reservoir and the train pipe, and to allow air to escape from the latter to the atmosphere. This has the effect of reducing the pressure in the train pipe to a given extent according to the amount allowed to escape and the length of the train. The reduction of train pipe pressure so actuates the triple valves that all communication between train pipe and auxiliary reservoirs and between brake cylinders and atmosphere is cut off, and, at the same time, air is allowed to flow from the reservoir to the cylinders until the pressure in the former is reduced to that in the train pipe. The pressure thus produced on the pistons applies the brake. When a reduction of pressure of from 20 to 25 lbs. per square inch is made in the train pipe, the pressure in the auxiliary reservoirs and brake cylinders is equalised, and the brakes are consequently applied with their maximum force.

To release the brakes air is re-admitted from the main reservoir to the train pipe thus restoring its pressure. This puts the triple valves into their original state, the auxiliary reservoirs are recharged to full pressure and the air in the brake cylinders is allowed to escape into the atmosphere, thus releasing the brakes.

In each brake van there is a cock by means of which the guard can allow air to escape from the train pipe, thus applying the brakes.

Should a train break away or should the train pipe burst or become broken in any way, all the air will, of course, escape from it thus applying the brakes with full force.

In Vacuum brakes a vacuum of about 20 inches of mercury is created in the train pipe by means of an " Ejector " on the engine. This apparatus extracts air in the same way as the blast pipe and chimney extract it from the smoke box of a locomotive. On each vehicle is a cylinder, the piston of which is suitably connected to the brake blocks. The cylinder is in connection with the train pipe on both sides of this piston, on one side directly, on the other, through the medium of a non-return valve which is so arranged that air can flow freely from cylinder to train pipe, but cannot flow in the opposite direction, from train pipe to cylinder. The same vacuum is thus produced in the cylinder, on both sides of the piston, as in the train pipe.

When running the vacuum is maintained against leakage by means of a small ejector of similar design to the large one used for creating it, or, in some cases, by means of a pump driven from the cross head of the engine.

When it is desired to apply the brakes, the driver admits air to the train pipe thus reducing the vacuum by an amount depending on the quantity of air admitted and the length of the train. The air which is admitted to the train pipe flows freely into the cylinder on one side of the piston, thus reducing the vacuum therein to an amount similar to that in the train pipe. On the other side, however, the entrance of air is stopped by the non-return valve, and the vacuum on that side of the piston is maintained. There being thus a difference of pressure on the two sides of the piston, it is drawn towards the side of least pressure, thus applying the brakes with a force proportional to the amount by which the train pipe vacuum is reduced. To apply the brakes with their maximum force, the vacuum must be completely destroyed.

To release the brakes the vacuum is recreated, thus again putting the pistons in equilibrium.

In each brake van there is a valve by means of which the guard can admit air to the train pipe, thus applying the brakes.

Should a train break away or should the train pipe become broken in any way the vacuum will be completely destroyed and the brakes applied with full force.

Such then are the main outlines of the operation of pressure and vacuum brakes respectively. Pressure brakes carry a supply of compressed air on each vehicle, which, when the brakes are to be applied, is allowed to flow into the brake cylinder, while, with vacuum brakes, a vacuum is normally maintained on both sides of the brake piston and the brakes applied by reducing or destroying it on one side only.

Each system has its advantages and disadvantages. The principal disadvantages of pressure brakes are that they are somewhat complicated and that they must be completely released or not at all. Methods of overcoming this latter difficulty and supplying a graduated release have been devised, but they add to the complication and are not in general use.

On the other hand Vacuum brakes are open to the objection that they are slower in action than pressure brakes and decidedly slow in release, also that, owing to the low pressure available (about 10 lbs. per square inch) the cylinders and pipes must be of considerable size.

The desirable features of a brake for the purpose under consideration may now be reviewed more in detail. The first is that it should be capable of stopping the train without uncomfortable shocks and oscillations and without putting any undue stress on the draw bars, and that it should be possible to apply it with full power without risk of sliding any of the wheels.

The weight and length of modern express trains, and of the vehicles of which they are formed, have added certain difficulties to the problem of providing a suitable brake which were absent in the days when continuous brakes first came into use.

If the brake blocks could be applied to all the wheels of a train at the same time and with the same relative force no stresses would be set up when stopping. In practice, however, this is usually far from being the case. Air is admitted to, or released from, the train pipe at the engine, and some time is necessary for the action to pass along the train. With a long train this may amount to five or six seconds or more. The brakes may thus be applied with considerable force on the front vehicles before they begin to act at all on the last vehicles. As a result, the latter are forced against the former, compressing all the buffer springs. When the brakes are fully applied throughout the train the retardation of the back part will be more or less equal to that of the front part, and, there thus being nothing to keep the buffer springs in a state of compression they will rebound, and, in doing so, give rise to uncomfortable surging of the coaches, and possibly the breakage of one or more of the couplings.

To avoid this state of things the brake must never be on much harder in the front than in the rear of the train. This can be effected in three ways, by reducing the power of the brake, by lengthening the time taken to apply the brake on each vehicle, that is, slowing the rate of rise of pressure in the brake cylinders, or by shortening, the time taken to transmit the brake action along the train.

For instance, suppose on a certain train the time elapsing between the first rise of pressure in the cylinder of the first vehicle, and in that of the last vehicle is five seconds, while the time elapsing between the first rise of pressure in any cylinder and the attainment of full pressure in that cylinder is three seconds, then the brake will be fully applied on the first vehicle two seconds before it begins to act on the last. If the brake is not capable of being applied very hard so that no very great retardation of the front part of the train is effected, this will not produce any harmful shocks. If the brake is a powerful one, however, very considerable shocks will be set up. Now, assuming this to be the case, if the rate of rise of pressure in each cylinder is considerably reduced so that it takes ten seconds instead of three seconds to attain full pressure, when the brake is fully applied on the first coach it will be applied with half power on the last, and the shocks will obviously be very much reduced. If, on the other hand, the time of transmission of brake action can be reduced from five seconds to one and a half seconds, the rate of rise of pressure in each cylinder remaining the same, the same effect will be produced, viz., when the brake is fully applied on the first coach it will be half applied on the last. In the latter case, however, this state of things occurs three seconds after the beginning of brake action, whereas, in the former case, it does not occur until ten seconds have elapsed.

From these considerations it will readily be seen that a very important point in brake design is to arrange for the action to be transmitted from one end of the train to the other in the shortest possible time, as the shorter this is, the more powerful may the brake be, and the greater may be the rate of rise of pressure in each brake cylinder without giving rise to dangerous and uncomfortable shocks. Thus, turning again to the hypothetical case considered above, in its original state the brake will be fully applied throughout the train in eight seconds, but this will give rise to dangerous shocks. If these shocks are eliminated by reducing the rate of rise of pressure in the brake cylinders the brake will take fifteen seconds to become fully applied ; while, if they are eliminated by speeding up the rate of transmission of action through the train it will be fully applied in four-and-a-half seconds, or less than one-third of the time necessary in the former case.

Another cause of stresses during a stop is uneven brake action. It is obvious that if the brake is applied much harder on some vehicles than on others such stresses will be set up. If the brake is applied harder on the front than on the back of the train it will be " bunched," i.e., the buffer springs will be compressed throughout the stop, while if it is applied harder on the back than on the front, the train will be " stretched," i.e., there will be a stress on the draw gear.

A group of coaches, in, the middle of a train which are more powerfully braked than the rest will tend to reduce their speed more rapidly than the rest of the train, thus stretching the front portion and bunching the back, while a group similarly situated but less powerfully braked than the rest, will produce the opposite effect, bunching the front portion and stretching the back.

Uneven brake action arises principally either from defective brake design or defective maintenance of the brake apparatus. Defective design may result in loss of brake power in a variety of ways, but this can be more conveniently dealt with at a later stage.

The most common cause of uneven brake action is uneven piston strokes due to the brakes not being properly adjusted. On all vehicles means are provided by which, as the brake blocks are worn away, the gear can be adjusted to compensate for this, so that the piston strokes may not be unduly increased. When this is neglected the increased piston stroke diminishes the brake power on that vehicle. This is so in the case of pressure brakes, because the air discharged from the auxiliary reservoir for any given reduction of the train pipe pressure, has to fill a larger cylinder space, and is, consequently, at a lower pressure. In the case of Vacuum brakes, the vacuum not being perfect, there is always *some* pressure in the cylinders. A vacuum of 20 inches corresponds to an absolute pressure of about 5 lbs. per square inch. When the brake is applied, although no air is admitted to the vacuum side of the piston (or reservoir, side, as it is usually called), the residual air, which is already there, is compressed to some extent by the movement of the piston and its pressure consequently raised. The longer the stroke of the piston the greater is the pressure thus produced and, consequently, the less is the difference in pressure on the two sides of the piston for any given reduction of train pipe vacuum.

Another cause of uneven brake action is leakage of air past the pistons on some vehicles, thus allowing the brake partially to leak off during the stop. In these cases the stresses set up, will be increasing throughout the stop.

Skidding of the wheels not only leads to noisy and rough riding, but may result in the loss of a considerable amount of brake power. This will be dealt with when considering the question of stopping the train in the minimum distance.

The second point laid down was that the brake should be at least sufficiently powerful to enable the train to run at the full speed necessary to keep time without any risk of over running the home signal should the distant signal be sighted at danger, even in foggy weather.

Modern express trains may, at times, be running at 80 miles per hour down a bank of 1 in 100. On down grades the distant signal is usually placed 1,000 yards from the home. To stop in this distance under these conditions is equivalent to stopping in about 878 yards from the same speed on the level, and requires an average retarding force of 8.12 per cent. of the weight of the train. Allowing a margin for safety it may be said that, in these circumstances, the brake should be capable of exerting an average retarding force of $8\frac{1}{2}$ per cent.

When a distant signal is less than the standard distance from the home, the next distant signal also is kept at danger if the home signal is " ON " so that 1,000 yards may be taken for the present purpose as the minimum distance in which it is necessary to stop on a down grade.

On the level, or on a rising grade not steeper than 1 in 200, 800 yards is the standard distance between distant and home signals. On the level 70, miles per hour may be taken as the maximum speed, and $8\frac{1}{2}$ per cent. retarding force will effect a stop from this speed in 642 yards.

On a rising gradient steeper than 1 in 200, 600 yards is the standard distance. Taking 55 miles per hour as the maximum speed on a 1 in 200 gradient, $8\frac{1}{2}$ per cent. retarding force will stop the train on such a bank in 374 yards.

Thus it may be said that a satisfactory brake for an express passenger train should be capable of exerting an average retarding force of at least $8\frac{1}{2}$ per cent. of the weight of the train.

The third point was that the brake should be capable of being released quickly, and the fourth that the release should be graduated. The desirability of these features is fairly obvious and nothing can profitably be added here to what has already been said about them.

The fifth point was that the brake must be capable of being applied by the guard as well as the driver, and that it must be automatic in its action, and it was remarked that these features are required by law of any brake used on British railways. They also are obviously desirable, and hardly need enlarging upon.

The last point laid down was that the brake should be capable of stopping the train quickly in case of emergency.

The retarding force which it is possible for a brake to produce is limited in various ways. The ultimate limit is the adhesive force between the wheels and the rails. When a brake block is applied to a wheel running upon a rail its tendency is to prevent the wheel from rolling on the rail and cause it to slide. The greater the friction between the block and the wheel the greater will be this tendency and the greater will be the retarding force, up to a certain point. The friction between the wheel and the rail which prevents the former from sliding on the latter (as the retardation of the brake block is tending to make it do) is of the nature of static friction and the maximum retardation is obtained when the limiting value of this friction has nearly been reached. Should it be passed, however, and the friction between the brake block and the wheel exceed that between the wheel and the rail, the wheel will slide. When this takes place the friction between wheel and rail becomes dynamic friction, and, as this is much less than static friction, the retarding force is considerably lessened. At the same time the friction between the brake block and wheel changes from dynamic to static and the brake block pressure must thus be very considerably lessened before the wheel will revolve again.

It is thus important, where maximum retarding force is required, to avoid all risk of sliding the wheels.

Dynamic friction varies according to the relative speed and the temperature of the substances in contact. The higher the relative speed and the lower the temperature, the less is the coefficient of friction. When the pressure between the brake block and wheel is constant this tends to equalise the coefficient of friction between them during a stop since the speed is falling and the temperature rising throughout it. As a matter of fact, however, the gain in friction due to the fall in speed more than compensates for the loss due to rise in temperature and the coefficient of friction between the brake block and wheel rises throughout the stop. This means that skidding will occur, if at all, towards the end of a stop or when the brake is applied with full force at low speeds. Thus, with ordinary brakes in which the maximum available pressure between the brake blocks and the wheels is constant, such maximum pressure must be limited to an amount which will not cause skidding at the lowest speeds. This pressure is somewhere about 80 per cent. to 85 per cent. of the weight on the wheels.

At high speeds the brake block pressure may be more than 200 per cent. of the weight on the wheel without producing skidding, hence it is obvious, from these considerations alone, that the maximum retarding force which can be produced, in practice, by the ordinary type of brake will fall considerably below that theoretically possible.

Devices have been introduced by means of which the brake block pressure may be reduced during a stop so that the friction between the blocks and the wheels remains constant, or approximately so, thus permitting a much higher initial brake block pressure to be used. Such devices, however, add to the complication of the brake mechanism and are not in general use.

As has already been pointed out, the speed at which the pressure may be allowed to rise in each brake cylinder without giving rise to undesirable stresses in the train is limited by the speed at which the action can be propagated through the train. It is thus doubly important, from the point of view of making a rapid stop, that this speed should be as high as possible. In an ideal brake the maximum brake block pressure would be obtained instantly on every vehicle. Suppose that on a given train, the minimum time in which the brakes can be fully applied is five seconds. For practical purposes this may be taken as equivalent for having no braking force for two and a half seconds, and then applying all the brakes instantly, at full force. A train running at 60 miles per hour will travel 73 yards in two and a half seconds, hence the delay in attaining full braking force alone will add about this distance to the length of the stop.

Much brake power may be lost through badly designed rigging. It is usual to take the brake block pressure on any vehicle as being the nominal pressure on the piston, or pistons, multiplied by the leverage given by the rigging, but, if the brake gear is not properly designed, it may actually be very much less than this. There is a limit to the leverage which can profitably be employed. A piston of a given area acting through a leverage of, say, 10 to 1 is nominally the same as one having half the area and acting through a leverage of 20 to 1, but actually the former is much more efficient than the latter. The greater leverage means that the piston has a longer stroke ; and the longer the stroke the less the pressure, as previously pointed out in dealing with the question of maintenance.

After a certain point is reached the gain in power due to increased leverage is equalled or surpassed by the loss of power due to decreased pressure. About 12 to 1 is the greatest leverage which can be profitably used. If this does not produce sufficient power a larger cylinder, or an additional cylinder must be used.

Again, to obtain the maximum effect from any brake rigging it must be so arranged that all rods lead away from the levers to which they are attached as nearly as possible at right angles to the latter.

It need hardly be pointed out that, to obtain maximum retarding force, the brake must be applied to every wheel in the train. This is not always the case in practice, however ; six-wheeled coaches in particular are frequently seen with the brake acting on four wheels only.

It is also obvious that all pipes and passages through which air flows into the brake cylinders must be of sufficient size to allow the pressure to rise with the maximum rapidity allowable.

From these considerations it will be apparent that the principal problems in designing a brake for modern express passenger trains are to get the brake action propagated through the train as rapidly as possible, to provide as much pressure between the brake blocks and, the wheels as is possible without skidding the latter, and to provide for a quick and graduated release.

In order to accelerate the transmission of the brake action, valves, usually called " Accelerating valves," have been provided on some of the vehicles of the train, or on all of them, which operate to produce a local reduction of train pipe pressure or vacuum. Air is thus flowing into, or out of, the train pipe at various points throughout the train, instead of at one point only. The earlier types of these valves were all arranged to operate only when a very quick stop was required to be made, and were brought into operation by opening the driver's valve on the engine to its full extent, thus allowing air to enter or escape from the train pipe more rapidly than was the case in making ordinary service applications.

For Vacuum brakes the principle upon which these accelerating valves work is as follows. Two chambers are provided, separated by a diaphragm. Both chambers are connected to the train pipe, the lower one through a comparatively large, and the upper one through a small hole. To the diaphragm is attached a valve which normally covers a hole on the train pipe. When a vacuum is created in the train pipe the two chambers are, of course, also exhausted, and the diaphragm is in equilibrium, having an equal vacuum on each side of it. When a slow reduction of vacuum is made in the train pipe, that in both chambers is reduced at the same rate and the diaphragm remains in equilibrium. If a rapid reduction is made in the train pipe, however, the vacuum in the lower chamber will be reduced more quickly than that in the upper one owing to the choking effect of the small hole through which the latter is connected to the train pipe. The diaphragm thus has a greater pressure on its lower than on its upper side and so rises, taking the valve with it, and thus uncovering the hole into the train pipe. This causes a rapid local reduction of vacuum which helps to operate the next accelerating valve and so on throughout the train.

With pressure brakes the accelerating valves are usually combined with the triple valves, and their action is rather more complicated, but the effect produced is the same.

Valves acting in this way are open to the objection that, if they are brought into action at all, the brake is fully applied. This involves the loss of any benefit from them in making ordinary service stops, and also renders it necessary that, either the engineman shall be sufficiently skilful to avoid operating the valves when he does not intend to, by making too rapid a reduction of pressure or vacuum, or that more or less complicated apparatus must be provided to prevent his being able to do so. Accordingly, accelerating valves have been designed by means of which a quick partial action is obtained, that is, a rapid reduction of train pipe pressure or vacuum is made throughout the train, but not to a sufficient extent to apply the brakes with anything like full power. This is usually brought about by allowing air to escape from or enter the train pipe, as the case may be, not directly to or from the atmosphere, but to or from a reservoir of restricted capacity. The same effect is produced, however, by arranging for the valve to close rapidly before much air can escape from or enter the train pipe.

Electrically operated valves have been devised by means of which the brakes may be applied simultaneously on each vehicle, but they are not, at present, very widely used.

The latest type of Westinghouse Brake in ordinary use on express trains has triple valves so arranged as to admit rapidly sufficient air to each brake cylinder to bring the brake blocks up to the wheels with a light pressure, each valve also causing a sudden local limited reduction of train pipe pressure which operates the next one and so on throughout the train. The subsequent increase of pressure in the cylinders takes place comparatively slowly.

The Vacuum Brake Company supply accelerating valves which can be applied to each vehicle, and will produce either a partial or full application, but neither type is in common use, in this country at any rate. The valve provided in each brake van, however, by means of which the guard can apply the brake, is arranged to open automatically when a rapid reduction of vacuum is made in the train pipe.

In the latest type of Vacuum Brake used on express trains on the Great Western Railway a valve is provided in connection with each brake cylinder, which is so arranged as to admit air to that cylinder, when a reduction of vacuum is made in the train pipe, in sufficient quantity to reduce the vacuum in it by a similar amount. Thus, in order to reduce the vacuum to any given amount, and so apply the brakes with any desired force, it is only necessary to admit sufficient air to reduce the vacuum in the train pipe alone to the desired figure, the air required by the cylinders being admitted to them directly from the atmosphere. This considerably accelerates the propagation of the brake action through the train.

The guard's valves in each brake van are also, arranged to open when a rapid reduction of vacuum is made, and to close again before it is completely destroyed.

In order to compensate for the difference in the coefficient of friction between the brake blocks and the wheels at high and low speeds, brakes have been designed which provide a high brake block pressure when first applied, but in which the cylinder pressure is allowed to leak down slowly so that, as the speed is reduced, the brake block pressure is correspondingly reduced.

Both the Westinghouse and Vacuum Brake Companies supply a leak-off valve for this purpose, but, as has, been previously remarked, they are not in general use.

Another means of compensating for this difference in coefficient of friction, which has been devised, consists of so attaching the brake blocks that they are free to move round the wheels to a limited extent, the movement being resisted by a spring. As the coefficient of friction between the blocks and the wheels increases, the tendency of the former, to move round the latter will correspondingly increase. The gear is so arranged, however, that such movement in either direction has the effect of diminishing the brake block pressure in proportion to the amount of movement. By this means the actual friction between, blocks and wheel is automatically kept constant throughout the stop ; as the coefficient increases the brake block pressure correspondingly decreases.

This arrangement is ingenious and theoretically ideal, but it adds materially to the complication of the brake gear.

Turning now to the question of quick graduated release, pressure brakes, lend themselves readily to the attainment of a quick release owing to the fact that, in releasing, the air is discharged from each cylinder to the atmosphere and air flows rapidly from, the main reservoir into the train pipe, and soon restores its pressure. With vacuum brakes, however, all the air from both cylinders and train pipe has to be extracted by the ejector.

On the other hand graduated release is readily obtained with Vacuum brakes. It is, in fact, inherent in their construction since, after applying the brakes, the vacuum can obviously be recreated ,to any desired extent, and thus any desired difference in vacuum can be produced between the two sides of the brake piston.

But with pressure brakes, as ordinarily made, *any* increase of train pipe pressure will discharge all the air from the brake cylinders and so completely release the brakes. Triple valves can be made which give a graduated release, but they are more complicated than the ordinary type, and are not widely used.

Such, in outline, are the principal points involved in the design of a brake for modern express passenger trains. To those familiar with brakes this paper will appear common-place enough. The Author has nothing new to lay before them. The work of the members of our Society lies, for the most part however, in other directions, and many of them have, no doubt, gone but little into the matter. The Author hopes that, to them, his remarks have not been altogether without interest.

DISCUSSION.

In opening the discussion, the Chairman said that the Author had given them a very interesting paper and one that would be a valuable addition to the Society's proceedings. He said that there seemed to him one point against the Vacuum brake, that was with regard to the keeping of the blocks properly adjusted. If they are not kept up to the wheel there is a falling off in efficiency. With the high leverage required to get the requisite power, in some cases 17 to one was necessary, if the brake blocks are not kept up, the piston finds itself at the top of the stroke without the blocks coming up to the wheel.

Mr. C. T. Cuss said that he had recently been looking through some Engineering books nearly 100 years old, and was much struck with the similarity of the means employed for checking trains in motion then and to-day. There was one exception, the old slipper brake had disappeared, this was forced down on to the rails, the weight of the vehicle being applied to the rail. He was rather surprised that more had not been done in the direction of a drum on the axles to brake on, instead of applying the brake block to the tyre. The factors against the usual practice were additional wear to the tyre, and the tendency of the brake blocks and gear to spread outwards, due to the tread of the tyre being coned 1 in 20, whilst the line of brake block application was longitudinal. Heating, loose tyres and difficulty of application in many cases should not be lost sight of.

Referring to the Chairman's remarks re leverage, the Author said that when he spoke of a leverage of 12 to 1, he was referring particularly to carriages, where a combined cylinder and reservoir was used. With locomotives it was sometimes necessary to adopt a bigger leverage, but this could be overcome by having greater reservoir space. Some time ago they had some trouble with the brakes of the " Great Bear." This was remedied by putting in an extra reservoir. The leverage was too great for the existing reservoir space. Regarding Mr. Cuss's remarks respecting the old system of stopping a train or vehicle by putting a skid on the rails, the great objection was that dynamic friction only was got between skid and rail, which is much less than the static friction between wheel and rail. The retarding force was only equal to that which would be obtained if the wheels were skidded. Regarding the idea of a drum on the axles, he certainly saw no objection to it except that it was an additional complication. He did not think the block wore away the tyre very much. The wear of the tyre due to rolling on the rail probably amounts to much more than that due to the brake block.

The Chairman said that regarding the remarks as to getting the pressure on the brake block to act at right angles to the tread of the wheel, experiments were now being carried out in that direction. Instead of the movement of the block being parallel to the centre line on the engine it was being tried at right angles to the 1 in 20 cone on the tyres.

Mr H. F. V. Dawson said that in his paper then Author had mentioned that one of the objections to the Vacuum Brake was the difficulty in re-creating the vacuum after putting the brake on. He did not know whether he had noticed that last year two patents were taken out. One was an electrically driven motor pump on two coaches in the train to help create the vacuum, and the other was a pump on two or three coaches, acting through the oscillation of the train. Could he tell them anything about this apparatus ?

The Author said he had heard nothing and therefore could tell them nothing about the apparatus referred to by Mr. Dawson, but he should be sceptical as to the practicability of that worked by oscillation. With regard to the motor driven pump, the only objection he could see to it was the expense.

Mr. W. H. Pearce said he thought the Author might have given some information relating to heavy engines running on light trains as regards graduated release. For instance, running down banks between Newton Abbot and Plymouth, the vacuum in the reservoir was partially destroyed by opening an aperture which resulted in decreasing the brake pressure of the engine only : the great advantage being to keep the tyres from overheating. There is also the action, of switching the pump on to the reservoir to maintain the vacuum therein, and so an even pressure throughout on the blocks, by overcoming any leakage. Also some examples of the advantages with the present type of Ejector on the Great Western Railway having the Steam valve separate from the Air valve, which was an additional advantage for running down banks. Steam can be kept on, thus tending to create a vacuum, and the air valve open to a sufficient degree to overcome this tendency to the extent required ; this gives a very variable release as compared with the old ejector, when there was control of either air or steam only.

The AUTHOR said that with regard to heavy engines on light trains the engine is generally the worst braked unit in the train. It is not always the same weight, as sometimes the boiler may be nearly full, and sometimes partially empty. An engine therefore cannot be braked up so highly as a coach, and generally the engine is pulling on the train during a stop if the train brake is properly designed. As to whether the engine was heavy or light he did not think that it made very much difference in that respect, although, of course, the heavier the engine and train the more stretch there is. The original object of switching the pump on the reservoir was simply cheapness of maintenance. With an engine having a separate reservoir and connecting pipes, as the riding is usually decidedly rougher than that of a coach, these pipes are liable to shake loose and so produce leaks. To maintain an efficient brake it is necessary to keep on doing light repairs. If the vacuum is maintained in the reservoir by means of the pump the apparatus can get in a much worse condition without impairing its efficiency than would be the case if the tightness of the reservoir, etc., were relied on alone. With regard to the separation of the Steam and Air valves, on the four cone Ejector, the main object was to make the handle work easily . It was thought that, with the large steam valve necessary in this ejector, if the ordinary type was adopted, it might be almost impossible to move it. Therefore a different type of steam valve altogether was adopted and a separate air valve. It certainly was a convenience to work the brake in the way described by Mr. Pearce, as the vacuum could be regulated much more exactly.

Mr. DAWSON said that the Author had remarked that the vacuum retaining valve was mainly to keep the vacuum in the reservoir because the engine was apt to ride rough and thereby cause leaks in the reservoir connections. He was under the impression that the idea was to cut the pump off the train pipe.

The AUTHOR replying, said that the effect of the pump on a train pipe having a 2in. hole in it, which is virtually the case when the air valve is fully open, is negligible. The retaining valve was adopted not to get the pump off the train pipe, but to get it on to the reservoir. In the Vacuum Brake Co's ejector, when the handle is right over in full emergency position, the little ejector is switched on to the reservoir. This has practically the same effect as the G.W.R. retaining valve, but it works only when a full application is made.

Mr. F. J. Bearman, referring to the idea of brake drums on trains, said that to put a brake block on an ordinary engine takes about seven minutes. He took it that these drums would be of cast-iron, with perhaps a liner. It would generally be found that these drums when subject to the pressure of the brake blocks would start overheating, and after a short period of use would get worn and have to be renewed. It seemed to him that it would be a big job getting them on and off, especially on a carriage where there was not much room.

Mr. Cuss said that whatever form of brake power you use you are bound to have some wear. An instance of brake power with little wear is in a road motor vehicle, where the engine is used as a brake. Has any practical work been done on similar lines on a Railway, and if not why not ? Could the Author tell them ? Lubricated brakes provide brake power with little loss of metal. Unlubricated brakes lose much metal, as can be seen on main lines, severe grades, etc.

The Author said the only thing of the kind he could think of that had been done was the practice, on electric trams and, in some cases, on electrically operated trains, of running the motors as dynamos in short circuit. This is an ideal retarding force, but it can only be utilised with electric traction.

Mr. K. J. Cook asked if it was not possible that if you were getting near the limit of adhesion between the wheels and rails and opened the regulator you would increase the braking force, and would be more likely to keep the wheels just turning. If the driving wheels come to a point where they are beginning to slip, you will still keep them turning, and also be enabled to keep the braking force. Illustrated in a Motor : If you put the engine out you can lock the wheels straight away. He took it that it would be a similar effect on a locomotive. He also asked if he correctly understood that the engine always, has more weight margin than the coaches, and that the coaches will slip first. In the case of any damage to the train pipe, is it possible to run with all the brakes released from the release cocks without any automatic working, or will the pump gradually exhaust from one side of the pistons and apply the brakes before it is completely exhausted ? Also, does it become positively dangerous with a long train, the length of time taken to apply brakes, because on noticing Vacuum braked goods trains one never seems to see the maximum number of trucks coupled that could be. One never sees more than about 15 coupled up. Would it be dangerous to have 30, 40, or even 50 coupled up ?

Replying to the first point, the Author said it would be the case. That is, if the wheels were just about to skid, putting on some steam would prevent them from skidding. It would be quite possible to release the brakes and run as a hand-braked train, and this is sometimes done. In any case the pump would not pump the brake on because it would re-create the vacuum on the train pipe side of the piston.

With regard to Vacuum fitted goods trains running with only 15 wagons, he said he thought Mr. Cook must be a little incorrect in his figures. If vacuum wagons were available they should be coupled up to 35 vehicles. What limits the number that can be coupled up is the power to maintain the vacuum against leaks. With regard to the stresses produced by the length of time required to get the brake on, the fact of having un-braked wagons behind accentuates the trouble referred to. If you have a long train and apply the brake powerfully on the front part of it before it is applied on the back part, you get a certain amount of bunching ; but if the back part of the train is un-braked, you never get the brake on there at all, and the bunching is necessarily increased.

Mr. Cook said he had seen in print instances of engines running away being put in reverse. He presumed, however, that this could never give a greater retarding force than with the brakes working normally .

The Author replied that as the engine alone is usually not braked up so high as the coaches there is a certain amount of margin if the boiler is full. Assuming that to be the case, there is some additional power ; but if you should over do it, and skid the wheels you would lose power.

Mr. Bearman said that he had often noticed with the brakes on suburban trains near London, when the train stops, the engine first stretches the couplings and then compresses the buffers. Was there any special reason ?

The Author said that the engine being less highly braked than the coaches, the train stretches the couplings as the stop is taking place, particularly at the end of the stop when the coaches grip, and the rebound is simply due to the spring in the draw gear.

Mr. A. T. Cheesley asked if there were any figures available with regard to the steam consumption of the two forms of brake gear under discussion, as that was a very important factor. He said that with regard to the Vacuum brake, he believed they had a great deal of trouble with sticking pistons. Was that trouble experienced to the same degree with the Westinghouse ? In the Westinghouse brake the piston is taken back into its position by means of a spring. Would it not be better if they fitted a spring to the Vacuum brake ? Some action appears to be set up on the piston rod of the vacuum cylinder by the India-rubber bush. Could the Author give them an idea of the exact action which takes place ? If you take the India-rubber bush and place it straight away on the gun-metal rod and leave it for an hour or so, it cannot be moved, and the bush has to be torn off. It might be a peculiarity of the metal, and he understood that with yellow brass the action is somewhat relieved. With regard to the brake block wearing on the tyre, everyone seemed to dismiss this very lightly, but he thought it was one of the points that should be gone into further, particularly with regard to carriage blocks. He said that in many cases when the blocks had a steel insert, in less than a week, due to the action of the brake blocks alone, he had seen over $\frac{3}{8}$in. wear on the tyre.

With regard to the steam consumption the Author said he was afraid he could not give any figures. He had not the figures of steam consumption for the Vacuum brake in his head, and with regard to the Westinghouse brake he had no idea what was the average steam consumption.

With regard to the action on the India-rubber gland, the sulphur seemed to combine in some way with some constituent of the gun-metal in the rod. He thought they had largely reduced the trouble by using yellow brass liners instead of gun-metal, as he had not heard much of the trouble recently.

Regarding the wear of the tyres with the steel insert, it seemed to him that this was mainly due to the out-station staff allowing the blocks to wear too far before changing them. It was cheaper to change blocks earlier than to allow the steel insert to go down on the tyre. It would be decidedly damaging to the tyre if it were allowed to wear against it for any length of time.

Mr. Cuss said that the steam consumption for Vacuum and Westinghouse brakes depended very largely on the length of the train, the condition of the connections, and the number of leakages. He said the leakages were very variable, but in both instances very extensive, and he thought that was one point which was worthy of much more attention than it received, so as to get greater reliability and much greater economy in the maintenance of brakes and steam. With regard to the adhesion of the rubber gland packing to the gun-metal sleeves on the piston rods, he said he had experienced the difficulty referred to, which was chemical action of the sulphur in the rubber on the gun-metal. He had overcome the difficulty for some purposes by tinning the gun-metal.

Mr. Cheesley reminded the Author that he had not answered his question re sticking pistons.

The Author said that, so far as he knew, the piston in the Westinghouse Brake was just as liable to stick as that in the Vacuum brake. On the coaches, the G.W.R. were making, as quickly as possible, heavier pistons to pull the brake off with more certainty, and, in the meantime, they were fitting springs to produce that effect. Of course, a spring was more necessary in the case of the Westinghouse than the Vacuum, as, owing to the piston being so much smaller it is much lighter. Also the normal cylinder used on coaches was horizontal, and in this case a spring was absolutely necessary.

Mr. Bearman enquired what actually happened in the way of stopping the train when the communication cord was pulled.

The Author replied that when the cord was pulled it opened a valve at the end of the coach and made a hole in the train pipe.

Mr E. H. Gooderson said that the Westinghouse brake was used in a good many places, and seemed to be quite successful in America, also in some places in this country. Which was the most costly — Westinghouse or Vacuum ?

The Author said it was generally supposed that the Westinghouse was the more costly to maintain. He had seen, however, some figures in connection with the cost of fitting and maintaining brakes by various railway companies, in which the differences between different railway companies using the same brake was often greater than the differences between the two brakes.

Mr. C. F. Insell asked whether anything had been done in the way of experiment with a larger brake block. On cranes, for instance, a band is used which goes completely round the drum. He wondered whether if they had a longer surface on the brake block it would tend to get a better retarding action. With regard to leakages, could the Author give a few details with regard to the couplings between coaches. He had often seen them couple up the coaches in a haphazard manner, especially at the end of the train, and he wondered what was the exact design of the coupling there.

With regard to longer brake blocks, the Author said he did not think they would get any increase of retarding force, but they would get less wear of the blocks.

With regard to Couplings, so far as the back of the train is concerned, the stop is simply a disc with a plug on it, and the end of the pipe may be considered in connection with it as a hole with a rubber ring round it. The end of the pipe rests on the disc, and is kept in position by the plug, and the suction of the vacuum holds it tight. All that is necessary is just to put it on.

Mr. Bearman said that on the Rail Motors a small ejector is used, and very often they seemed short of steam. Would it not be more economical to have a pump on them ?

The AUTHOR said that the reason a pump was not used on the Rail Motors was that it could not be got there.

In closing the discussion the CHAIRMAN said that though the Great Western Railway was the only Railway Company running with 25in., this was really due to the fact that no one else had got an ejector which would create that Vacuum, and as the result of experiments carried out by the G.W.R. Technical Staff, the present Vacuum Brake, as fitted by the G.W.R. Company, was far superior to any other vacuum brake fitted by a Railway Company or put on the market by a commercial firm.