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THE ELECTRO-PNEUMATIC BRAKE SYSTEM FOR STEAM ROAD SERVICE.¹

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In a paper read before the members of this Institute some eighteen months ago, the speaker had something to say regarding air brakes. In this the importance of the air brake in general was given prominence. This evening an attempt will be made to impress upon you the great value of applying electricity as the means of operating the pneumatic or compressed-air brake, the effect of which is obtained by transforming the fluid pressure into a mechanical force, the energy of the vehicle being dissipated by friction between the brake shoes and the wheels of the vehicle.

It has long been known that electricity could add to the flexibility and efficiency of a compressed-air brake, but, so far as steam road equipment is concerned, there are four chief reasons why it has not heretofore been employed for this purpose:

¹Read by Mr. Walter V. Turner at the meeting of the Mechanical and Engineering Section held Thursday, April 4, 1912.

[NOTE.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.]

First.—Electric current has not been available without special provision being made for it.

Second.—We have not had sufficient knowledge or material at hand to insure a reliable current and connections.

Third.—Because the present air brake has been sufficiently flexible and near enough to being simultaneous for the conditions up to quite recently.

Fourth.—That the pneumatic brake had not been brought to such a degree of perfection as would warrant the application of electricity to it.

(1) Now, however, current is available on practically all the steam trunk lines, as well as on electric railway and steam road electrifications, as nearly all first-class trains are lighted by electricity.

(2) Now the art has developed into a science, in that reliable information and data are at hand with which to make practicable applications, and jumper connections have been brought to such a state of simplicity and reliability that there is no longer need for fear in these respects.

(3) As affecting the action and results of the operation of the pneumatic brake, at least two serious changes in conditions have occurred:

First.—Heavier vehicles.

Second.—Longer trains.

In addition to this, time has become much more important than heretofore because, (1) by congestion of traffic, particularly adjacent to large cities, and (2) because the time lapse as a factor in controlling trains composed of heavy vehicles with the pneumatic brake has become quite serious.

The time element in the brake operation is very important in two ways. In one, it is very necessary, and in the other very undesirable. First, for service operations a time interval is necessary in some steps of the operation; for instance, while it is important that the brake commences to apply on each vehicle of a train simultaneously, it is equally important that the development of the force be obtained gradually, and both these for the same reason, namely, the elimination of damaging shocks and discomforting surges to or in the train. The simultaneous application prevents the slack from first running in and then out, and so on; while the slow rise of cylinder pressure prevents a too

sudden and rapid change of motion,—that is, deceleration, with its consequent disagreeable effect upon the passengers. In emergencies the time element is very undesirable, as to stop is then the only consideration, the requirement being that the consequences be less disastrous than if the accident had not been avoided.

With regard to time, so far as traffic is concerned, every second saved between stations means an increase in the number of passengers it is possible to carry on the same track, as well as a reduction in the schedule time, more trains possible in the same time, and consequently greater realization of the object of running a railroad.

With regard to the time affecting results of pneumatic brake operation, this is manifested with long trains in the increase of time necessary to get the brake applied, and by shocks and stresses, due to the different designs of brake apparatus, or force at the front and rear of the train, at the same instant, and the more rapidly it is attempted to apply the brakes (when rapidity does not include simultaneous action) the greater will be the shocks and stresses. Moreover, when passenger rolling stock has been brought to its present state or condition for the comfort of travellers, any shortcomings, or lack of improvements in this respect, stand out very prominently by contrast, and this is particularly true of what is probably the only remaining two improvements to be made in modern trains, namely, the discomforts produced by the starting and stopping of these trains.

The application of electric current to the brake will not only eliminate the shocks and surges that occur with even the present slow service rate of brake application, but will permit of the application being made more rapidly throughout the train as a whole; thus, as above mentioned, being the equivalent of much more efficient motive power. This will be understood when it is considered that a train in motion is, in effect, a power plant, having a potential the utilization of which can be spread over many minutes, on the one hand, or condensed into a few seconds, on the other. That is, the train may be *permitted* to dissipate its energy in minutes or *compelled* to do it in seconds. Another way to look at this is that a train in motion with the power cut off is the waste product of the power-house (and usually most of it goes to waste, since it is not utilized to save time), and to-day

it is to the heretofore waste product, turned into by-product, that many businesses owe their melon feasts.

With regard to the fourth proposition or assertion, namely, that the pneumatic brake has not until recently reached such a stage as would warrant its being actuated electrically, we may say that electricity would not in any sense add to the braking force, its purpose being to produce simultaneous operation; the application of the brake, in other respects, being identical with the ordinary pneumatic operations. The chief purpose in adding electricity to a pneumatic brake is to instantly transmit the intent of the engineer or operator to each vehicle of the train, thus eliminating the time element and, other things being equal, all shocks and stresses, both in service and emergency, and, in emergency, to shorten the stop somewhat by producing instantaneous application of the brakes on all vehicles in the train.

In the last year or two vehicles have become so large and heavy and trains so long because of large locomotives that the time element between the application and release of the brake from the engine to the last car has become a quite serious factor, since it permits the slack to run in or out, as the case may be, producing discomforting and sometimes dangerous shocks. Operating the service brakes electrically under such conditions then will eliminate this, while, in emergency, it will serve the twofold purpose of preventing shocks and shortening the stops. The retarding force, it must be understood, comes solely from the pneumatic portion of the brake, and until such a brake is installed that will produce the maximum emergency retardation desired or permissible, actuating the brake electrically will not only be a very expensive way to seek improvement, but will be far inferior in results to what could be done pneumatically.

Hereinafter we expect to have more to say on this phase of the matter and to illustrate it by graphic charts; therefore, it may be sufficient to state here that adding electric operation to the old brake, while it will improve matters here wonderfully so far as comfort is concerned, yet it will not compare with what can be done with the strictly pneumatic brake in the matter of stopping force. As the pneumatic brake is now sufficiently developed to warrant the application of electric control and transmission, it reduces to simply a question of expense and wisdom.

Before going into the design of the electro-pneumatic brake, it may be well to show some of its advantageous features and to emphasize the importance of improving the pneumatic brake to its highest degree, before adding electric features, by showing a few curves illustrative of the characteristics of the various improvements or changes in results.

The various curves to follow show comparative performances of service and emergency operation. The advantages of the electro-pneumatic equipment over the strictly pneumatic equipment are clearly shown in Figs. 1, 2, and 3.

The results shown on these curves represent service and emergency stops made from a speed of 40 miles per hour with a 10-car train equipped with the electro-pneumatic brake and an 8-car train equipped with the old-style equipment (P. M.).

Curves 1 and 2 on each figure illustrate the relative decrease in speed as the stop is approached, and curves 3 and 4 show the relative percentage of braking power developed.

The full line curves in each case represent the improved equipment, and the dotted line curves the old equipment.

Fig. 1 represents comparative stops made with a typical service application of the brakes in each case. These curves are plotted on a *time* base to permit of more directly representing the *time saved* and *economy factor* of the electro-pneumatic equipment as compared with the old pneumatic equipment. It will be seen that with the average manipulation, characteristic of the two types of equipment, there is a saving of 20 seconds in the time of stop, in favor of the electro-pneumatic equipment.

It will be evident that this shortening of the time of the stop is due to the fact that a *higher braking power* is obtained in a *shorter time*, and that the service action is started *simultaneously* on each car, as compared with serial action with the old pneumatic equipment.

This high percentage of braking power is permissible with the electro-pneumatic equipment by reason of the great flexibility of this equipment; that is, the simultaneous action permits of a high braking force at the start, while the speed is high, and by means of the graduated release feature the braking force can be gradually reduced as the speed of the train decreases.

With the old pneumatic equipment not having the graduated

release feature the serial action in applying the brake, required different manipulations and would not permit of the use of high braking force if smoothness of stop was to be considered.

The maximum braking power with the new equipment (as shown by Curve No. 3), 108 per cent., was obtained in about $4\frac{1}{2}$ seconds, and was retained for about 11 seconds longer, or until the speed of the train had been reduced to about 14 miles per hour, after which the brake was graduated off, the train coming to a stop, with the braking power reduced to 29 per cent. This curve may then be considered as a typical braking power curve showing the graduated release stop.

FIG. 1.

The maximum braking power with the old equipment, (as shown by Curve No. 4), $67\frac{1}{2}$ per cent., was obtained after a lapse of 16 seconds and was retained for about 13 seconds longer, or until the speed of the train was reduced to about 14 miles per hour, at which time the brake valve was moved to release and back to lap, and then a second application was made, the train coming to a stop with the braking power about $33\frac{3}{4}$ per cent. This curve may then be considered a typical braking power curve showing the usual two-application stop, which is the nearest approach to the graduated release possible with the old equipment.

It will be noted that at the time the 10-car (electro-pneumatic) train has come to a stop, the 8-car (old equipment) train

is still moving at a speed of 25 miles per hour ($62\frac{1}{2}$ per cent. of its initial speed), with about 39 per cent. of its original energy still remaining to be overcome before it can be brought to a standstill.

This shortening in the time of stop makes possible—higher speeds and shorter schedules, with consequent increased traffic capacity with the same number of cars and power consumption; or the *same* traffic capacity with *fewer cars*; or the same average speeds, schedules, and traffic capacity with *less* power consumption, since the power may be shut off sooner and the train allowed to drift or coast for 11 seconds (645 feet) before applying the brakes to make the stop at the same point.

To further show the difference in the two brake equipments, it is only necessary to mention that if two trains were started on parallel tracks at the same station and both attained the maximum speed, the train equipped with the electro-pneumatic brake would have reached the next station, stopped, discharged passengers, taken on passengers, and be started again before the train equipped with the old brake would have made its stop at the same point.

Even with this possibility of making service stops in a much shorter time, and thus increasing the traffic capacity of the system, there still remains the necessity of keeping the signals spaced the same distance as before, unless the emergency features of the brake are improved as well as the service.

But with the emergency brake improved, and the ability to stop the train in a much shorter distance, as shown by the curves on Fig. 3, it is possible to decrease the distance between signals and still maintain even greater safety than before.

It is possible then to not only run on a much less headway, and in some cases double the number of trains operating over the road, but also longer trains may be operated, since, by the simultaneous and uniform action of the brakes, shocks and stresses are reduced to a minimum, thereby permitting a greater number of passengers to be carried without discomfort, because of the greater number of cars per train and the smooth action of the brake.

Fig. 2 represents comparative stops made with an emergency application of the brakes in each case. These curves are plotted on a *distance* base to compare the *length of stop* and relative

safety factor of the two equipments. It will be seen that the stop with the train having the electro-pneumatic equipment is made in a much shorter distance and less time than that with the old equipment. At the 350 foot mark where the electro-pneumatic train stopped, the other is moving at a speed of 28.3 miles per hour (71 per cent. of its initial speed), with 50 per cent. of its original energy still remaining to be overcome before the train comes to a standstill. At the time the electro-pneumatic train stopped, the old equipment train has run 140 feet farther and is still moving at a speed of 20.2 miles per hour, representing 25.5 per cent. of its original energy.

FIG. 2.

This shortening of the stopping distance with the electro-pneumatic train results from the increased percentage of braking power over that obtained with the old equipment train and also to the fact that *simultaneous* emergency action is obtained throughout the train, as against *serial* action with the old equipment.

It will be noted that the maximum braking power in the old equipment train was only 79 per cent., and was obtained at about 150 feet from the point where the brakes were applied; while 120 per cent. braking power was obtained in the electro-pneumatic train after it had run about 40 feet from the point where the brakes were applied.

Fig. 3 represents comparative stops made with an emergency application of the brakes on an 8-car old equipment train and a 10-car train equipped with the most improved electro-pneumatic brake (main reservoir pressure used in emergency).

The maximum braking power obtained with the improved electro-pneumatic equipment is 175 per cent., as against 79 per cent. with the old equipment. The latter train ran 650 feet before coming to a stop, while the former train was brought to a standstill in 275 feet. As the old equipment (P. M.) train passed the point where the improved electro-pneumatic equipment train stopped, it was running at a speed of 31.9 miles per

FIG. 3.

hour ($79\frac{3}{4}$ per cent. of the initial speed), with $63\frac{1}{2}$ per cent. of its original energy; and at the time the improved electro-pneumatic train was brought to a stop, the old equipment train was still running at the rate of 22.8 miles per hour (57 per cent. of its initial speed), with $37\frac{1}{2}$ per cent. of its original energy remaining.

By comparing the curves for the electro-pneumatic equipment and the improved electro-pneumatic equipment, it will be seen that the braking power for the latter is greater than the former by 35 per cent. and its stopping distance is 75 feet shorter. This is due to the fact that main reservoir pressure

(approximately 100 pounds) is obtained in emergency operations, thus giving the high braking power.

To further show the immense value and powerful effectiveness of the improved form of electro-pneumatic brake, the following might be added:

The 10-car train, weighing 331 tons and running at a speed of 40 miles per hour, has a kinetic or "wrecking" energy of 17,800 foot tons, equivalent to raising a *ton weight* to the height

FIG. 4.

of 17,800 feet, or to raising the *whole train* to a height of 54 feet.

This energy is entirely dissipated by the brake and the train brought to a stop in $9\frac{1}{4}$ seconds, and in a distance of 275 feet from the point where the brakes were applied.

Fig. 4 shows four diagrams. Diagram No. 1 illustrates the great difference in the rate of brake pipe reduction between a 5-car and a 100-car train when making a pneumatic service application. Comparing the results obtained from the two trains, it will be seen that with the 5-car train the brake pipe reduction

started immediately, and in 6 seconds time a 20-pound reduction was obtained; while with the 100-car train the reduction did not start until 20 seconds time, and it required 75 seconds to obtain a 20-pound reduction.

Diagram No. 2 shows the rise in brake cylinder pressure resulting from the brake pipe reduction shown in Diagram No. 1, and is proportional thereto.

Diagram No. 3 shows the drop in brake pipe pressure.

Diagram No. 4 shows the rise in brake cylinder pressure resulting from an electro-pneumatic service application. Since the electro-pneumatic operation is simultaneous, the same brake pipe and brake cylinder cards would be obtained on every car in the train, regardless of the length of the train.

The advantages of the electro-pneumatic equipment are clearly shown here, as the time element is entirely eliminated, resulting in each car starting to do its share of braking simultaneously.

This simultaneous action of the brake eliminates the disastrous results due to the slack between the cars running in and causing shocks.

Fig. 5 shows two diagrams. The upper diagram illustrates an electro-pneumatic service brake application, showing the start of rise in brake cylinder pressure in 1.9 seconds and the maximum cylinder pressure obtained in 5.5 seconds, and all brakes applying simultaneously.

Owing to the simultaneous action of the brakes throughout the train, the braking power can be developed in a short time without discomfort to the passengers.

The lower diagram shows the results obtained from a pneumatic service brake application on a 10-car train. The time for starting the rise in brake cylinder pressure is shown as 2.75 seconds, and the time for obtaining the maximum brake cylinder pressure was 11 seconds. The difference in time between the first and tenth cars, in start of rise in brake cylinder pressure, was one second.

Fig. 6 shows two diagrams. The upper diagram illustrates the results obtained from an electro-pneumatic emergency application on a 10-car train.

The lower diagram shows the results obtained from a pneumatic emergency application on a 10-car train.

Comparing these diagrams, it will be seen that the only difference is in the time of transmission, and is all that should be claimed for the electric feature of the apparatus for emergency operation.

Fig. 7 shows two sets of curves. The upper curves illustrates the results obtained from a pneumatic emergency application with the "P.C." equipment. The maximum brake cylinder pressure was obtained in 2.8 seconds, resulting in a braking power of 180 per cent.

FIG. 5.

The lower curves show the results obtained from a pneumatic emergency application with a double "P.M." equipment (a complete brake equipment for each truck). The maximum brake cylinder pressure was obtained in 5.6 seconds, resulting in a braking power of 114 per cent.

These curves graphically illustrate the great difference that exists between different equipments, and that greater gain can be had by improving the pneumatic portion of the brake than by adding the electric features to the old equipment.

Comparing the work done by the two equipments, we will consider the stopping of two 10-car trains running at 60 miles per hour, the energy in these trains being 120.4 foot tons per ton weight. The train equipped with "P.C." equipment will stop in 575 feet shorter distance than the train equipped with the "P.M." equipment. If the train having the "P.M." equipment had the electric features added, without any other improvement, the stop would be shortened only about 70 feet; therefore, the stopping distance would still be 500 feet longer than with the

FIG. 6.

train equipped with the latest improved automatic features ("P.C." equipment). This, because adding the electric features merely eliminates the time of transmission, the greater benefit being prevention of serious shocks and of break-in-twos.

ELECTRO-PNEUMATIC BRAKES.

Difference in the conditions to be met, and certain advantages that might be employed with profit, have led to the development and commercializing of four chief types, or forms, of electro-

pneumatic equipments, of which some distinctions can be mentioned.

Traffic conditions, such as exist on the Interborough Rapid Transit Company's subways, very fittingly illustrate the necessity, as well as the advantages, of the electro-pneumatic system of brakes.

At the present time this road is carrying over one million passengers per day, and to handle this large number of people

FIG. 7.

it is necessary to run trains of 10 cars at speeds as high as 40 miles per hour, and on a headway of 90 seconds.

In order to maintain the schedules with these heavy trains and to enable a train to stop, discharge passengers and start again without, in any way, delaying the following train, the highest permissible rates of acceleration and retardation are necessary. To obtain the former, new and improved motive power was installed with which it is possible to obtain a rate of acceleration of $1\frac{1}{2}$ miles per hour per second (about three times that possible with the modern heavy passenger locomotive). To

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FIG. 8.

obtain the latter, since the time element of the serial operation of the best and quickest automatic air brake made the 90-second headway impossible, it was necessary to install a new and improved system of brakes.

Not only is time an important factor, but smoothness of operation is essential on account of the number of passengers standing, who in the case of rough stops are often injured, which is not only bad for them, but costs the railways much money for damages, etc.

The impossibility of the automatic air brake to handle the situation led to the development of an electrically-controlled air brake, the electrical equipment being an addition to the improved automatic brake, the highest order of pneumatic brake still being available in the event of a failure of the electrical attachments.

The principle of operation of the automatic brake is the same as described by your orator in a former paper read before this Institute.

The electrical operation will be described in what follows:

Fig. 8 is a piping and wiring diagram of this equipment as applied to the Interborough Rapid Transit Company's subway cars. This plate plainly shows the relationship existing between the automatic and the electro-pneumatic brakes, and that the latter can be added to any automatic brake equipment already in service.

This equipment consists of the standard Westinghouse Company's "AMR" equipment, some of which apparatus has been modified, and the following new apparatus:

The motorman's brake valve, which is the operating valve of this equipment, has been slightly modified by the addition of a revolving drum (carrying contacts) and four stationary contact fingers; this drum closes the circuit across the several fingers in the various electrical positions and thus causes the several electrical brake operations as desired by the motorman.

The *triple valve*, held in reserve, and used only in case of accident to, or disability of, the electrical features, has had a magnet and magnet valve added to its cylinder cap so that (by closing the proper circuit, which can be done by throwing the brake valve to the emergency position) *instantaneous* quick action is obtained throughout the train instead of serial quick action as heretofore.

The check valve case of this valve was changed so that the rubber-seated valve (formerly the emergency valve) allows the supplementary reservoir air to equalize with the brake cylinder and auxiliary reservoir, thus giving a higher maximum emergency cylinder pressure in less time than formerly.

The *electro-pneumatic brake pipe vent valve* is a new device which automatically vents brake pipe air to the atmosphere (thus causing serial quick action throughout the train) whenever a given rate of brake pipe reduction is exceeded. The operation of this valve in emergency also closes the circuit to the emergency magnet line, so that an instantaneous quick action or emergency is obtained whenever current is "on."

Another new device is the *application and release magnet bracket*. This device, as the name implies, consists of two magnets and magnet valves by means of which air can be admitted to, or exhausted from, the brake cylinder at the will of the motor-man by the manipulation of the brake valve.

The various parts will now be described in detail.

Fig. 9.—The *ME-21 brake valve* is the operating valve for this equipment, and is composed of two distinct parts—one electrical, the other pneumatic. These two portions are mounted on the same shaft and are operated by one and the same handle.

The pneumatic portion of this valve is the same as former types of valves, but the electrical features are new and are placed above the pneumatic portion, and consist of a revolving drum attached to the same shaft as the rotary valve. This drum has four contacts which connect with corresponding contact fingers when the valve is rotated through its various positions.

The upper finger is connected direct to the trolley, the second finger to the application magnet line, the third to the release magnet line, and the lower one to the emergency magnet line.

The release magnet valve is normally open, hence there is no current flowing through the brake valve when in the electrical release position, which is also the running position for the pneumatic brake, and any air that is in the brake cylinder can flow to the atmosphere and cause the release of the brake.

In the electrical lap position, the upper and third fingers are in contact with the drum, closing the release magnet line circuit, energizing the release magnet, closing the release magnet valve and separating the brake cylinder from the atmosphere; in the

electrical service position, the first, second, and third fingers are in contact with the drum, and current is still flowing through the release magnet; the application magnet line circuit is also closed, thus opening the application valve, which, in turn, opens the relay valve and allows auxiliary reservoir air to charge the brake cylinder.

In all electrical positions of the brake valve the brake pipe charging port is open, thus maintaining the brake pipe and auxiliary reservoir air at initial pressure. In the pneumatic lap position all ports are blanked. In the first pneumatic service position there is a small port open from the brake pipe to the atmosphere, which gives a suitable rate of brake pipe reduction to cause a service application on a 5-car train.

In the pneumatic lap position and first service position the electrical connections remain the same as in electrical application position; these connections are maintained in these positions to insure getting a brake application in case the motorman should move his brake valve beyond the electric application position.

In the second pneumatic service position there are two ports open from the brake pipe to the atmosphere which give a suitable rate of brake pipe reduction to cause a service application on a 10-car train.

In the emergency position there is a large port opening from the brake pipe to the atmosphere which gives a rapid enough rate of brake pipe reduction to cause the brake pipe vent valves to operate in quick action. At the same time connection is made between the trolley and emergency line contacts so that, if the current is "on," the emergency line and magnet are energized and cause the emergency magnet valve to open, and this, in turn, forces the triple valve over to the emergency position; thus, with current "on," the electro-pneumatic emergency will prevail, otherwise purely pneumatic emergency will result.

Fig. 10 shows a diagrammatic cut of the *R-2-C triple valve*, which is used with this equipment. This is the standard R-2 triple valve slightly modified by embodying a new cylinder cap having a magnet and magnet valve, and a new check case.

The magnet on the cylinder cap is connected to the emergency magnet line and is energized whenever this circuit is closed (which closing may be caused by the brake valve being moved to the emergency position, or by the brake pipe vent valve

FIG. 9.

closing its switch, due to burst hose or pipe, or separated train, etc.). This, in turn, opens the emergency magnet valve and connects the triple valve piston cylinder to the atmosphere, and since this cylinder is charged through a 1/16-inch choke, its pressure drops to zero almost instantly and causes the triple valve to go into the emergency position.

FIG. 10.

The check valve case was modified by removing the ordinary brake pipe check valve and supplying a small rubber-seated valve for the quick recharge and quick service features of the triple valve. The emergency valve is still embodied in the valve, but its duties are somewhat changed, in that supplementary reservoir pressure is now under this valve instead of brake pipe as hereto-

fore. Thus, when the triple valve moves to the emergency position, air from the auxiliary reservoir forces the emergency piston downward, unseats the emergency valve, and permits the supplementary reservoir air to equalize with the brake cylinder and auxiliary reservoir. By the use of this large valve the maximum brake cylinder pressure is of higher value and is obtained more quickly than was formerly the case.

This change in the check valve case makes this a plain auto-

FIG. 11.

matic instead of a quick action automatic, triple valve as previously, and, consequently, since trains of more than five cars are to be handled, it will be necessary to have a brake pipe venting device in the equipment.

Fig. 11 shows the *electro-pneumatic brake pipe vent valve*, standard for this installation. This valve is placed in the branch pipe leading from the brake pipe to the triple valve, and is composed of a small reservoir and a body which encases a double or

telescoping piston device. Brake pipe air enters the cored passage leading directly through the reservoir portion and flows through same to the brake pipe connection of the triple valve; this cored passage has a side outlet which leads down to the top of double piston, forcing both down against their seats, so that brake pipe air cannot escape around the lower end of the large piston's stem, and air from the chamber under the large piston cannot escape past the lower end of the small piston to the atmosphere. The chamber inside of the small piston is always open to the atmosphere by means of the small vent through the screw (which holds its seat in place) and the large piston stem.

Brake pipe air, which is always present above the double piston, is free to flow through the feed groove and charge the reservoir in the largest portion of the valve. This feed groove and reservoir are so proportioned to each other that during service brake pipe reductions the air in the reservoir can flow back through this feed groove into the brake pipe and thence to the atmosphere, and the pistons remain in their release or normal position. But if this service rate of brake pipe reduction be exceeded, the feed groove cannot accommodate the volume of this reservoir and, consequently, the pistons will be lifted out of their normal positions and moved to the emergency position. In this position the large piston rests against the reservoir gasket and the small piston is still down against its seat. With the pistons thus, the lower end of the large piston stem opens the ports in its bushing and also through its seat, thus allowing brake pipe air to escape through these ports to the atmosphere. The small piston is still seated downward, and remains there until the brake pipe air above it, which is reducing in pressure, and the reservoir air beneath it, which remains practically at initial pressure, have a differential of about 40 pounds, when it will be moved upward and brought to rest against its valve seat. This 40-pound differential is necessary, owing to the small area exposed to reservoir pressure, as against full area of the piston to the brake pipe pressure. When this piston lifts and seats upward, the row of ports around its lower end are opened, and the reservoir air can then drain to the atmosphere. When this reservoir pressure has dropped to a point slightly lower than that in the brake pipe, the large piston will be returned to its normal or release position, the smaller piston remaining seated upward until the brake pipe pressure is again restored.

FIG. 12.

The raising of the pistons, due to the sudden reduction of brake pipe air, also raises the copper disk which is attached by a small rod to the large piston stem; this disk closes the circuit between the trolley and the emergency magnet lines by connecting the two contacts shown in the lower portion of the valve.

Thus, if current is "on," the instantaneous emergency will prevail, but if current is "off," the venting of brake pipe air at any vent valve causes the next nearest vent valve to operate, and thus the serial venting of brake pipe air, and, consequently, emergency action is propagated throughout the train.

Figs. 12 and 13 will be considered jointly.

FIG. 13.

Fig. 12 is a vertical section taken through the magnets and valves of the application and release magnet bracket. From this view you will see that the two magnets are nearly identical and that, by means of their armatures and stems, they operate two valves. The release magnet armature stem and release valve are integral, and this valve is normally open, so that the brake cylinder is normally connected to the atmosphere. The application magnet armature stem operates a separate valve, which valve is normally closed.

Fig. 13 is another view of this bracket, showing a section through the relay valve and the special choke fitting or cap nut.

The magnet bracket has three pipe connections, viz., the supply from the auxiliary reservoir, the brake cylinder pipe, which connects the relay valve to the brake cylinder, and the release pipe, which connects the triple valve exhaust outlet to the magnet bracket. The exhaust opening is also tapped and may or may not be piped to carry the exhaust of the brake cylinder air away from the magnet bracket.

When an electro-pneumatic brake application is desired, the motorman moves his brake valve handle to the electric service position, but in doing so he must pass over the electric lap position, in which the release magnet is energized and its valve closed. Thus the cored passage leading from the brake cylinder to the atmosphere, *via* the triple valve exhaust port, is closed, and any air admitted to the brake cylinder will be retained there. With the brake valve in electric service position the release magnet is held energized, and the application magnet is also energized. This pulls the application magnet armature downward, and its stem forces the application valve from its seat and vents the top of the relay valve to the brake cylinder. Auxiliary reservoir pressure is always present under the outer area of this valve, and by means of a small drilled hole this air can equalize into the chamber above the relay valve, and thus, since the inner area of the under side of this valve is connected to the brake cylinder and thence *via* the release magnet to the atmosphere, the same is held seated. The relay valve chamber is connected to the under side of the application valve, and this chamber is normally bottled up.

When the application magnet is energized and the application valve opened the relay valve chamber is connected to the brake cylinder. This causes a drop in pressure which the small drilled equalizing port cannot supply, and consequently the relay valve is lifted by the auxiliary reservoir air, and the latter is allowed to flow down past this valve and through the special choke cap nut into the brake cylinder.

If the application magnet is energized for an instant and then de-energized, allowing the application valve to close, the pressures above and below the relay valve will very quickly equalize, closing this valve and permitting only a partial application of the brake. This operation may be repeated several times until the maximum brake cylinder pressure is obtained.

If the maximum pressure is desired quickly, the application

magnet is held energized by allowing the brake valve to remain in electric service position. Under these conditions, the relay valve will remain open until the auxiliary reservoir and brake cylinder pressures have equalized, or, if desired, as is here the case, the relay valve may be loaded with a spring, thus making it an excess pressure valve, in which case the brake cylinder pressure will be less than the equalization of the auxiliary reservoir and brake cylinder pressures by an amount equal to the tension of the relay valve spring.

For example, if the tension of this spring represents 10 pounds per square inch on the valve area of the relay valve, then the highest electro-pneumatic service cylinder pressure will fall 10 pounds below the equalizing point of the auxiliary reservoir and brake cylinder pressures, and since the triple valve remains in release position and the brake pipe keeps the auxiliary reservoir pressure at 70 pounds, this brake cylinder will be 70—10, or 60 pounds.

Since the triple valve remains in release position during an electro-pneumatic application, the air admitted to the brake cylinder by the relay valve is free to flow back through the triple valve exhaust port and the magnet bracket release pipe to the under side of the release magnet valve. Then, when the electro-pneumatic release of the brakes is desired, the brake valve is returned to the electric release position, in which the release magnet circuit is broken and the release magnet de-energized. The brake cylinder air then lifts the release magnet valve and flows past the same to the atmosphere.

This release may be made straight away or may be graduated at the will of the motorman.

To graduate the electro-pneumatic release, the motorman moves his brake valve handle to the electric release position for an instant and then back to the electric lap position. By this manipulation the release magnet is de-energized and then is again energized. This permits the release magnet valve to stay open for a few seconds only, and, consequently, a partial or graduated release of the cylinder pressure takes place.

The admission of air to the brake cylinder is direct, so that the rate of rise of brake cylinder pressure may be made whatever is desired, and may also be controlled by the special choke cap nut in the magnet bracket, the area of which choke is made proportional to the brake cylinder volume with which the magnet bracket

is to be used, so that the rate of increase of brake cylinder pressure will be uniform for all sizes of brake cylinders.

The release of the brake cylinder pressure is made through the triple valve exhaust, so that the time of release will be the same for either automatic or electro-pneumatic operation; this also eliminates the necessity of a double check valve or similar device which would otherwise be required to separate the two methods of operation.

The relay valve is used so that we may have an amply large opening between the auxiliary reservoir and the brake cylinder to give the cylinder pressure desired in the required time and still enable this opening to be controlled by a comparatively small magnet.

Fig. 14. The *master brake switch*, with its "no-voltage magnet," further safeguards the brake operation and the train movements.

This device consists of a rotating drum having eight contacts and eight corresponding stationary contact fingers, these contacts and fingers being used in the various positions of the switch. The drum aforementioned is mounted on a shaft which has provision for a suitable handle, so that this drum may be moved to any of its four positions.

The arrangements of the stationary and drum contacts are shown on Fig. 14 (upper right-hand corner).

There are four positions for this switch. The first is the one in which no current is flowing to the brake valve or brake apparatus, and is the one in which the switch is placed on all except the operating end of the controlling car in the train. Thus all the brake valves are "dead," except the one at the front end of the first car, and this must necessarily be so because the brake valves are carried in pneumatic lap position on all except this car, and when in pneumatic lap position the trolley, application, and release contacts are bearing against the contact drum. In the second position current is flowing to the brake valve, vent valve, and no-voltage magnet, but the application and release magnet lines are cut out. In the third position all connections are made except to the vent valve; and in the fourth position all electrical connections are closed, so that the entire electro-pneumatic system is available. This is the position for the switch on the controlling end of the train.

The handle of this switch is guarded so that it cannot be re-

moved (as is the case when the motorman leaves his train), except in the first position, in which all electrical connections are broken.

On the lower end of the drum shaft is a small rotary valve

FIG. 14.

which controls air communication between the "emergency valve" and the no-voltage magnet. This communication is closed in first position, but is open in the other positions.

The "no-voltage magnet" is what the name implies; to its armature is attached a valve and stem, which normally closes the

opening from the emergency valve through the emergency pipe and the small rotary valve of the master brake switch to the atmosphere: Whenever the voltage drops low enough to render the electro-pneumatic brakes ineffective, this magnet cannot hold its valve closed against the pressure under it, and thus allows the air from the emergency valve to be vented to the atmosphere and cause an automatic emergency application of the brakes. The switch can now be reset by moving its handle to the first position, and the brakes may then be released pneumatically.

This feature absolutely safeguards against serious accidents or delays which might result from a loss of voltage, and is of particular value where a train is drifting. Otherwise, under these conditions (drifting), the current might fail, and the motorman would be unaware of this failure until he tried to make a brake application, and even then his train would run some distance before he realized that the brakes were inoperative, and by this time even a pneumatic emergency might be unable to prevent collision.

The latest "*synchronizing of pump labor*" scheme, with which, after the system has once been fully charged, one master governor (whichever has the highest "cutting-in" point) will control all the compressors in the train as a unit, consequently the danger of any one compressor running continuously is eliminated.

The foregoing is a description of the electro-pneumatic system as applied to the subway division of the Interborough Rapid Transit Railway of New York City in 1910.

The operation of, and the returns from, the systems have more than met expectations. Also, the equipment has gone a long way to establish the electro-pneumatic brake on a permanent basis, since it has proven itself the safest, most profitable and economical type of brake equipment.

(To be continued.)

Resistance and Thermo-electricity of Tantalum. H. PÉCHEUX. (*Mon. Sci.*, ii, 842, 137.)—The resistance increases with the purity of the tantalum filament. The principal coefficient of temperature increases with the purity of the metal. The thermo-electric power increases with the purity of the tantalum. Annealing increases the thermo-electric power.