INTERBOROUGH RAPID TRANSIT COMPANY, NEW YORK.
ELECTRO-PNEUMATIC INTERLOCKING AND SIGNALING

BULLETIN No. 21

REVISED REPRINT

The Block Signal and Interlocking System of the Subway Division of the Interborough Rapid Transit Company

EARLY in the development of plans for the subway rapid transit system in New York City, it was foreseen that the efficiency of operation of a road with so heavy a traffic as was expected would depend largely upon the completeness of the block signaling and interlocking systems which should be adopted for facilitating the spacing of trains and the protection of train movements. The consideration of provision of signals at once appeared to be rivaled in importance only by that of the provision of the proper motive power. Not only for the safety of passengers, but also for facilitating the operation under such heavy and exacting schedules, it was decided to install the most complete and effective signaling system which was to be had.

Early in 1901 a careful study of available systems of signaling and interlocking was instituted in order to develop a system for the subway which should be especially adapted to the conditions of operation and fulfill the particular requirements met in the subway. The problem involved three prime considerations:

First, safety and reliability.

Second, the greatest capacity of the line consistent with safety and reliability.

Third, facility of operation under necessarily restricted yard and track conditions.

In order to obtain the above desiderata, with special reference to the question of safety of train movement, it was decided to install a complete automatic block-signaling system for the high-speed express lines in the subway, and block operation for all obscure points on the low-speed routes, and to operate all switches, both for line movements and in yards, by power from central points, through interlocking plants. This necessarily involved the inter-connection of the block and switch movements at many locations and made the adoption of the most flexible and compact plans essential.

The study of modern signaling and methods of protecting train movements indicated that the Westinghouse electro-pneumatic block and interlocking system promised the most satisfactory results if used under such exacting and severe conditions of operation as are to be experienced in the subway. The electro-pneumatic system has been thoroughly tested and tried, and found reliable under all conditions of weather and service. By it power can be readily conducted in small pipes in any quantity and to any distance, and utilized in compact apparatus in the most restricted spaces. The movements can be made with the greatest promptness and certainty, and inter-connected for the most complicated situations to provide absolute safety of train movement.

One of the most important features of the considerations in favor of the electro-pneumatic system is, moreover, that all essential details of the system have been worked out in many years of practical operation on important trunk lines of steam railroads, so that its reliability and efficiency are beyond question. It has rendered perfect service under some of the most difficult conditions that are to be found in railroad operation; at such terminals as those at Jersey City, Philadelphia and Pittsburgh, upon the Pennsylvania Railroad, at the terminal stations in Boston, Mass., and elsewhere, this system has operated successfully for many years in the most complicated track and switching conditions that can be imagined.

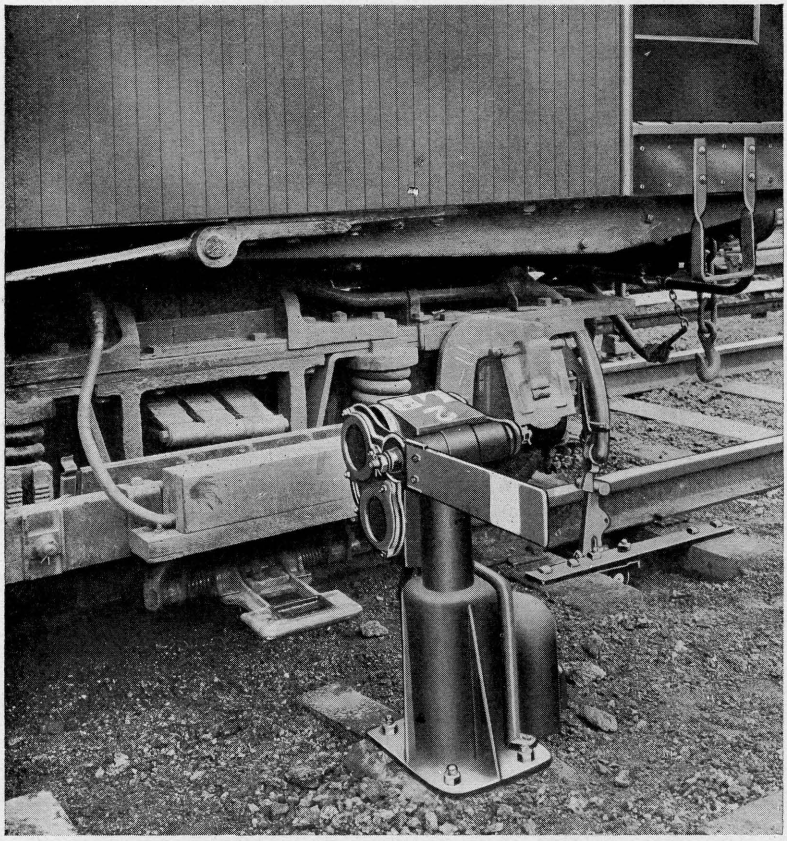
This system has also been applied to heavy electric railway service with marked success. It has been in use upon the Boston Elevated Railway system since its opening to the public, this being the first electric railway system to adopt a complete system of block signaling. In a more recent installation of block signaling which has been made upon the North Shore Road, an important third-rail electric system terminating at San Francisco, Cal., a system of electrically operated signals has been installed and has been in operation for nearly a year, which embodies the essential features of track circuits and signal control involved in the electro-pneumatic system.

Traffic Conditions

The New York subway operation as proposed, contemplated traffic of unprecedented density and consequent magnitude of propulsion currents employed, and experience with existing track-circuit control systems led to the conclusion that some modification in apparatus was essential to prevent derangement, which might occasion traffic delays. On account of this consideration, and others, the application of the signaling system to the subway conditions has evolved an elaboration of detail not before attempted upon any railway line of similar length, and it is believed that the contract for this installation is the largest single order ever given to a signal manufacturing company.

As elsewhere noted, the proposed operation contemplates two tracks loaded with local trains at one-minute intervals, and two tracks with eight-car express trains at two-minute intervals, the latter class of trains requiring at times as much as 2000 hp for each train in motion. It is readily seen, then, that combinations of trains in motion may at certain times occur which will throw enormous demands for power upon a given section of the road. The electricity conveying this power flows back through the track rails to the power station, and in so doing is subject to a "drop" or loss in the rails which varies in amount according to the power demands. This causes disturbances in the signal track circuit in proportion to the amount of "drop," and it was believed that under the extreme conditions above mentioned the ordinary form of track circuit might prove unreliable and cause delay in traffic. A solution of the difficulty was suggested, consisting in the employment of a current in the signal track circuit which would have such characteristic differences from that used to propel the trains as would operate selectively upon an apparatus which would in turn control the signal. Alternating current supplied this want on account of its inductive properties, and was adopted, after a demonstration of its practicability under similar condition on another electric railway.

Aside from the above modification the system follows the general lines of that which was worked out for the Boston Elevated Railroad, the first electric railway operating under heavy

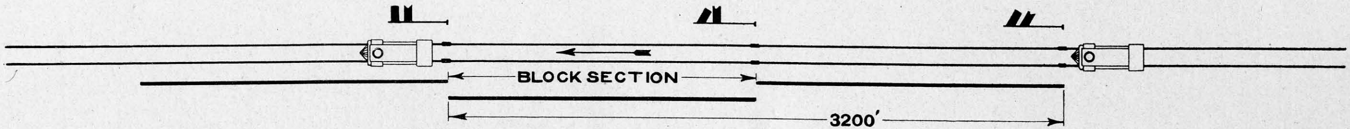


LENOX AVENUE YARD, DWARF SIGNAL AND AUTOMATIC TRAIN STOP traffic conditions, which adopted a complete automatic block-signal system with track-circuit control, and in which one of the track rails is devoted to the signal-control system and the other to the propulsion-current return. The use of the alternating current track circuits involved the adaptation of specially designed alternating current relays, which should in turn control the signal circuits, and at the same time be entirely unaffected by direct current disturbances. The system designed, it is thought, provides for all possible disturbing conditions and will be representative of the latest and best practice in railway signaling.

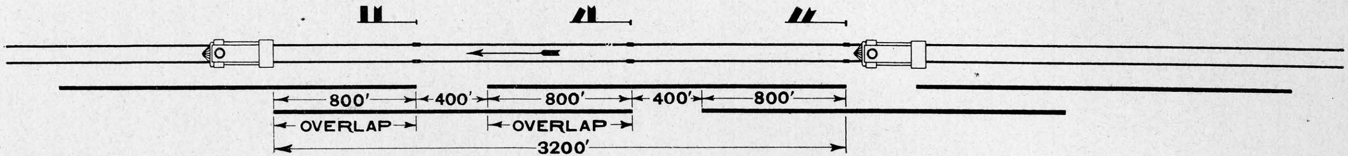
The Sub-division of Tracks Into Block Sections

On the assumption that trains are always under the control of their runners and that block signals are always visible in time for the exercise of that control, a single signal at the entrance of each block section is sufficient for safety. Since signals so arranged would, under many conditions, not be visible to enginemen sufficiently early to insure obedience to their warnings, the need for a second set of signals for repeating the indications of the first set has become a part of all modern block systems.

These signals, known as "distant" or "caution" signals, are preferably so located that each shall precede its home signal a distance equal to the braking distance of the heaviest train moving at its highest rated speed. Where the schedule does not demand close headway between trains, this braking distance may be considerably less than the length of the block section. In such cases, the distant signals may be entirely separate structures located at some intermediate point between the home or block signals. When the traffic is so dense as to call for block sections of the shortest lengths consistent with safety, "braking distance" becomes the limiting factor, and this distance determines the length of block. In such cases the location of the distant signal coincides with the location of the home signal of the preceding block, and it is customary to put the two on a common support, and, incidentally, to operate them both from a common local source of energy when this proves advantageous.

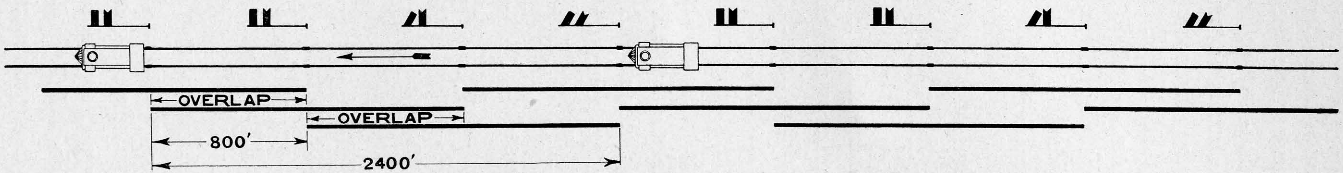


"A" BLOCK SYSTEM, WITHOUT OVERLAPS.



"B" BLOCK SYSTEM, WITH OVERLAPS.

THE BLOCK SECTION EQUAL TO TWO OVERLAPS AND A BLOCK SECTION.



"C" BLOCK SYSTEM, WITH OVERLAPS.

THE BLOCK SECTION EQUAL TO TWO OVERLAPS.

DISTANCE BETWEEN SIGNALS,	SHOWN IN FIG. A- 1600′,	FIG. B- 1200′,	FIG. C- 800′.
DISTANCE BETWEEN TRAINS,	SHOWN IN FIG. A- 3200′,	" B- 3200′,	" C- 2400′.
HEADWAY AT 25 M. P. H.	SHOWN IN FIG. A- 96 SEC.	" B- 96 SEC.	" C- 78 SEC.

DIAGRAM OF THE THREE PRINCIPAL METHODS OF BLOCK SIGNALING, INDICATING THE USE OF OVERLAPS

The very evident need, in the case of the Interborough, for utilizing, to the fullest extent, every inch of track space obtainable, was conspicuous from the beginning of the work, and the block lengths were, therefore, spaced from charts previously compiled to show the braking distances existing throughout the entire line.

Naturally, these lengths varied with the grades, and, to some extent, with the curvature of the tracks, so that uniformity was not wholly possible in the spacing of the signals, though uniformity in the design of the signals used, home and distant on the same support, was adhered to.

Automatic Stops and Two Red Signals

The system as outlined in the foregoing chapter covered the needs of the case *only under the assumption therein made respecting the constant control of trains by their runners.* But impaired vision, faulty judgment, and other influences, affecting even the most alert, must also be reckoned with, as must possible failures of apparatus; and on this road of extreme density of passenger traffic, these influences called for more than ordinary consideration. It was decided, therefore, to use automatic train stops. The stop apparatus as designed and installed will be described later. Furthermore, it was obvious that if automatic stops were to be relied upon for complete protection of the trains, the circuits must be overlapped; that is, if a stop is placed at a home signal B, for instance, the next home signal in the rear, A, (and its stop) must not be cleared until the train has gone a safe braking distance beyond B. But in the subway scheme the block length was practically braking distance. So it naturally came about that the overlap was the length of a block and the final development of the plan was two red signals behind each train. Diagram A illustrates the system of control without overlaps, as described above. Fig. B shows the same system with overlapping control, in which the block sections exceed in lengths the requirements of the braking system in stopping trains, while the home and distant signals are mounted upon the same posts for convenience and simplicity, rather than upon separate posts, as might be done at a somewhat greater cost and

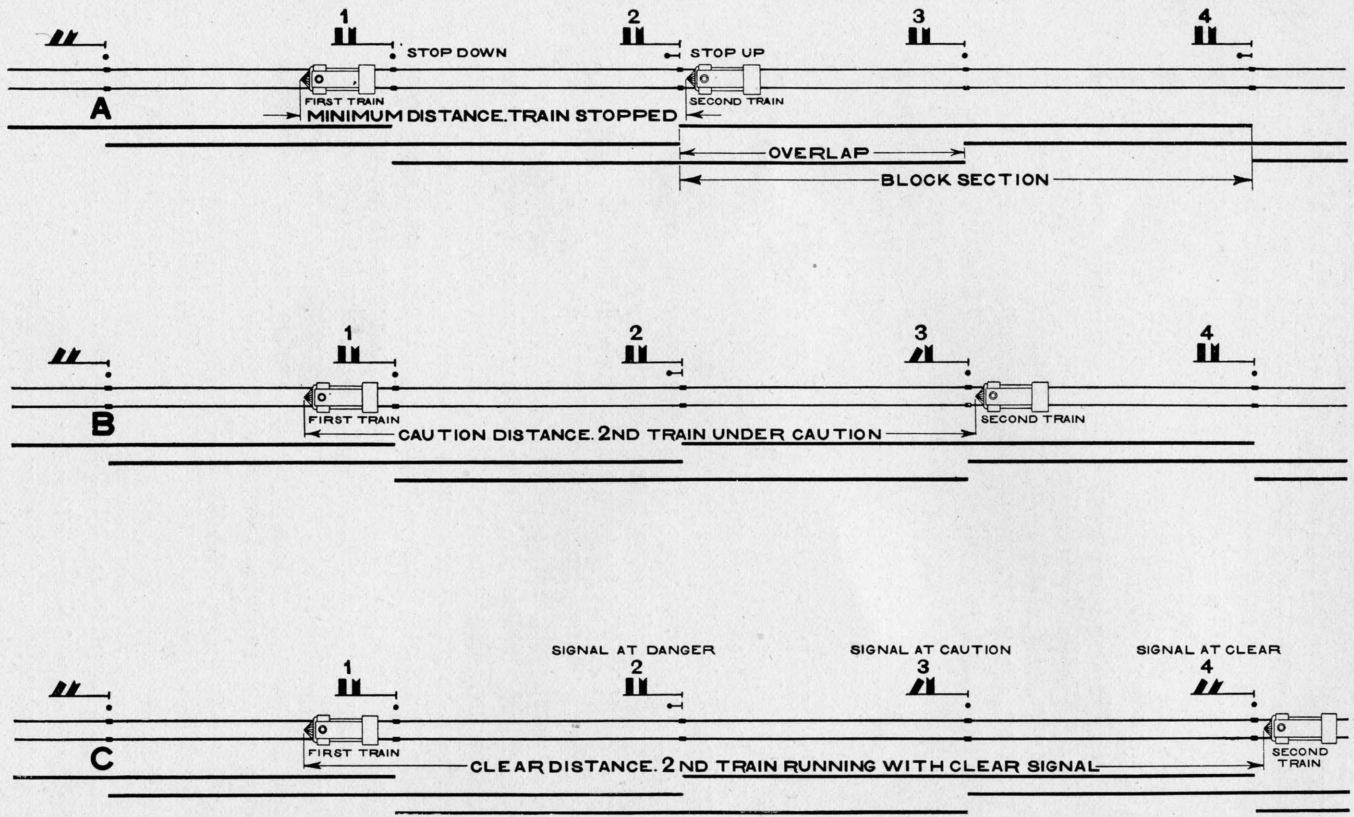


DIAGRAM OF THE OVERLAPPING BLOCK-SIGNAL SYSTEM ADOPTED, ILLUSTRATING POSSIBLE POSITIONS OF TRAINS RUNNING UNDER THEM complication if it were of material importance to place the distant signal no farther from the home signal than is required for braking distance between them.

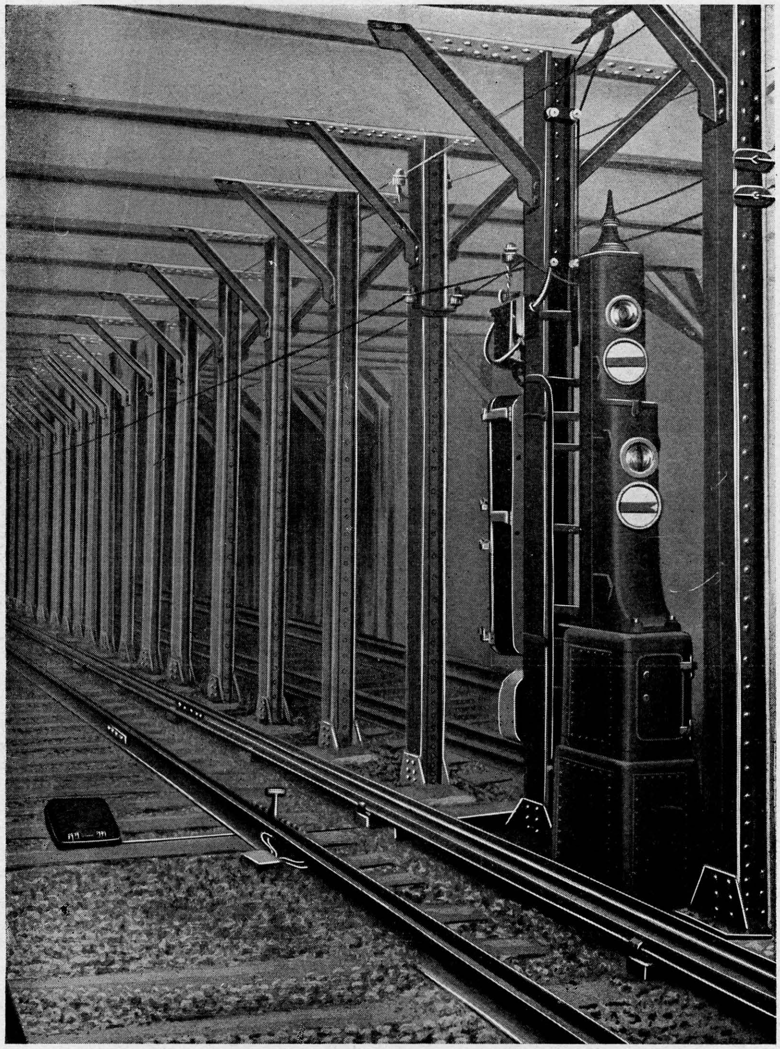
Fig. C shows the signals spaced braking distance apart, and, hence, the shortest possible blocks that can be employed consistently with safety. The overlap sections, in such cases, must of necessity embrace the entire length of track lying beyond the next two succeeding signals. Such an arrangement compels the spacing of trains farther apart than without overlaps and materially reduces the capacity of the road for simultaneous train movements.

The length of each block was given very careful consideration by the Interborough Company, who instituted a series of tests of the braking power of trains. From these tests and others made by the Pennsylvania Railroad Company, curves were computed so as to determine the distance in which trains could be stopped at various rates of speed on a level track, with corrections for rising and falling grades to 2 per cent. Speed curves were then plotted for the trains on the entire line, showing at each point the maximum possible speed, with the gear ratio of the motors adopted. A joint consideration of the speeds, braking efforts and profile of the road were then used to determine at every point on the line the minmum allowable distance between trains, so that the train in the rear could be stopped by the automatic application of the brakes before reaching a train which might be standing at a signal in advance.

In order to provide for adverse conditions, the actual braking distances were increased by 50 per cent—for example, the braking distance of a train moving 35 miles an hour is 465 ft.; this would be increased 50 per cent and the overlap made not less than 697 ft. With this length of overlap, home signals could be located 697 ft. apart, and the block section length would be double this, or 1,394 ft. The average length of overlaps, as laid out, is about 800 ft., and the average length of block sections double this, or about 1,600 ft.

The protection provided by this unique arrangement of signals is shown in the diagram on the opposite page. Three positions of trains are shown:

"A." Minimum Distance Between Trains—The first train has just passed the home signal; the second train is stopped by the home signal in the rear—if this train had failed



FRONT VIEW OF A TYPICAL BLOCK SIGNAL IN THE SUBWAY, SHOWING LIGHTS, POSITION INDICATORS, INSTRUMENT CASE UPON THE POST IN ADVANCE AND ALSO THE TRACK TRAIN STOP to stop at this point, the automatic stop would have applied the air brake and the train would have had the overlap distance in which to stop before it could reach the rear of the train in advance. Therefore, under the worst conditions, no train can get closer to the train in advance than the length of the overlap, and this is in all cases a safe stopping distance.

"B." Caution Distance Between Trains—The first train in same position as in "A" the second train at the third home signal in the rear. The latter signal can be passed under caution. This distance between trains is the caution distance, and is always equal to the length of the block section, or two overlaps.

"C." Clear Distance Between Trains—First train in same position as in "A;" second train at the fourth home signal in the rear. At this point both the home and distant signals are clear, and the distance between the trains is now the clear running distance; that is, when the trains are one block section plus an overlap apart, they can move under clear signal, and this distance is used in determining the running schedule. It will be noted in "C" that the first train has the following protection: Home signals 1 and 2 in stop position, together with the automatic stop at signal 2 in position to stop a train; distant signals 1, 2 and 3 all at caution; or, in other words, a train that has stopped is always protected by two home signals in its rear, and by three caution signals; in addition to this an automatic stop placed at a safe stopping distance in the rear of the train.

The application of continuous train speed curves, in combination with braking curves, to the line profile for the purpose of regulating safe overlap lengths, is believed to be entirely novel and to constitute an important advance in signaling lines for dense traffic. This system was suggested by Mr. Gibbs, and the tests for its adaptation were carried out under his direction.

Description of Block-Signaling System

The block-signaling system as installed consists of the automatic overlapping system above described, applied to the two middle express tracks between City Hall and Ninety-sixth street, a distance of 6½ miles, or 13 miles of track; and to the

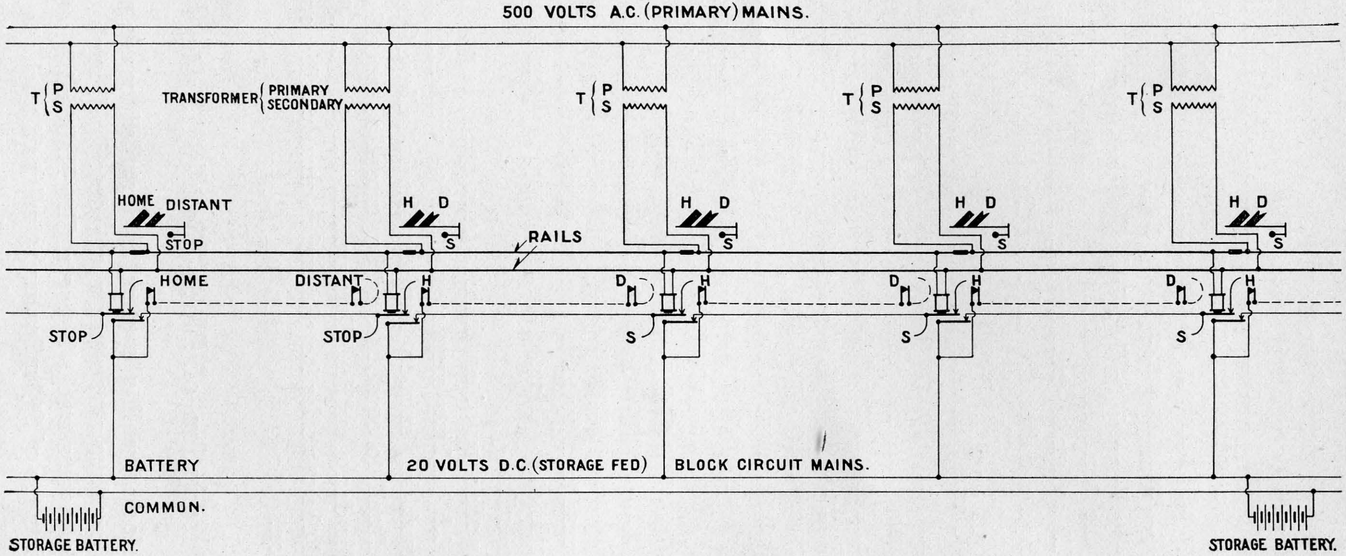
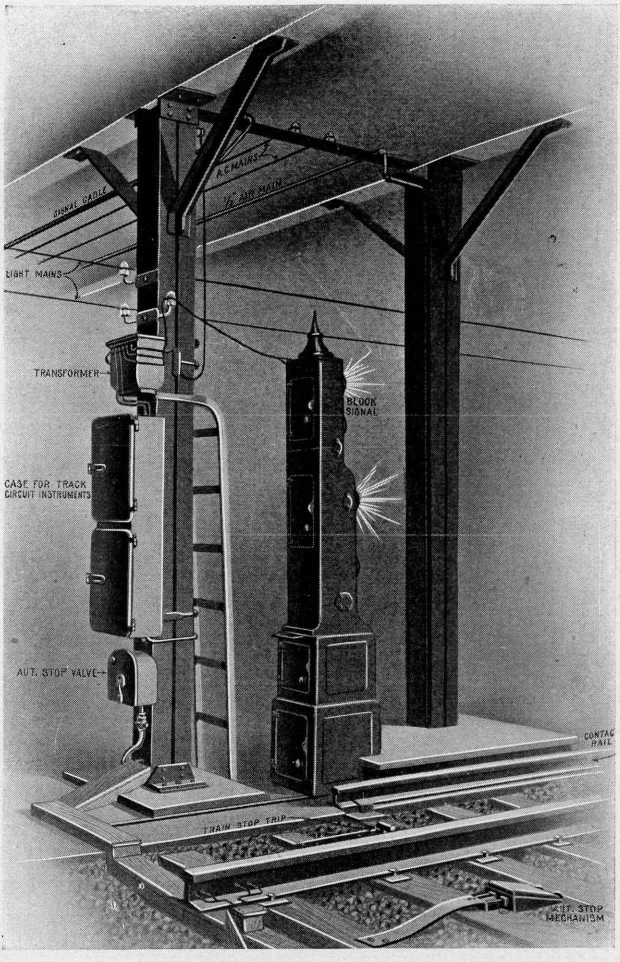


DIAGRAM OF THE BLOCK SIGNAL AND AUTOMATIC TRACK STOP CIRCUIT third track between Ninety-sixth street junction and 145th street on the west side branch, a distance of $2\frac{1}{2}$ miles. This third track, which is placed between the two local tracks, and will be used for express traffic in both directions, trains moving toward the City Hall in the morning and in the opposite direction at night, will be equipped with a special single-track system for indicating in either direction. Also the two tracks from 145th Street to Dyckman Street, a distance of $2\frac{1}{2}$ miles, or 5 miles of track, and the portion of the tunnel under Central Park, for a distance of $1\frac{1}{2}$ miles, or 3 miles single track, will be protected by signals. The total length of track to be protected by signals is $27\frac{1}{2}$ miles. The local tracks of the system will also be provided with block signals at important places, such as curves, stations, cross-overs, etc., and at the Harlem River tunnel.

The apparatus used differs little in general principle from that employed in earlier automatic systems of block signaling, the substitution of alternating-current in place of battery current for the track circuits, and the necessary alternating-current auxiliary apparatus, constituting the principal change. In detail of application to the peculiar requirements under subway conditions, however, the system embodies many radical features which are of unusual interest and importance. Great care has been given to the design, construction and installation of the signal apparatus, so as to insure reliability of operation under the most adverse conditions, and to provide for accessibility to all the parts for convenience in maintenance. On the opposite page is shown a diagram of the block signal and automatic train stop circuits as used in connection with the overlapping feature of this system.

In the study of this system of signaling, it is important to note that, in accordance with the latest practice in block signaling for electric railway conditions, one of the running rails of each track is insulated from the propulsion-current return system and is devoted to the signal system. Thus, the other rail performs the novel function of serving simultaneously as conductor for the direct-current return for the propulsion system, as well as that of one of the conductors for the alternating-current track circuit for controlling the signals. In accordance with the usual manner of arranging track circuits in block signaling, the current is fed into each block at the end from which the passing train leaves it, the connections to the

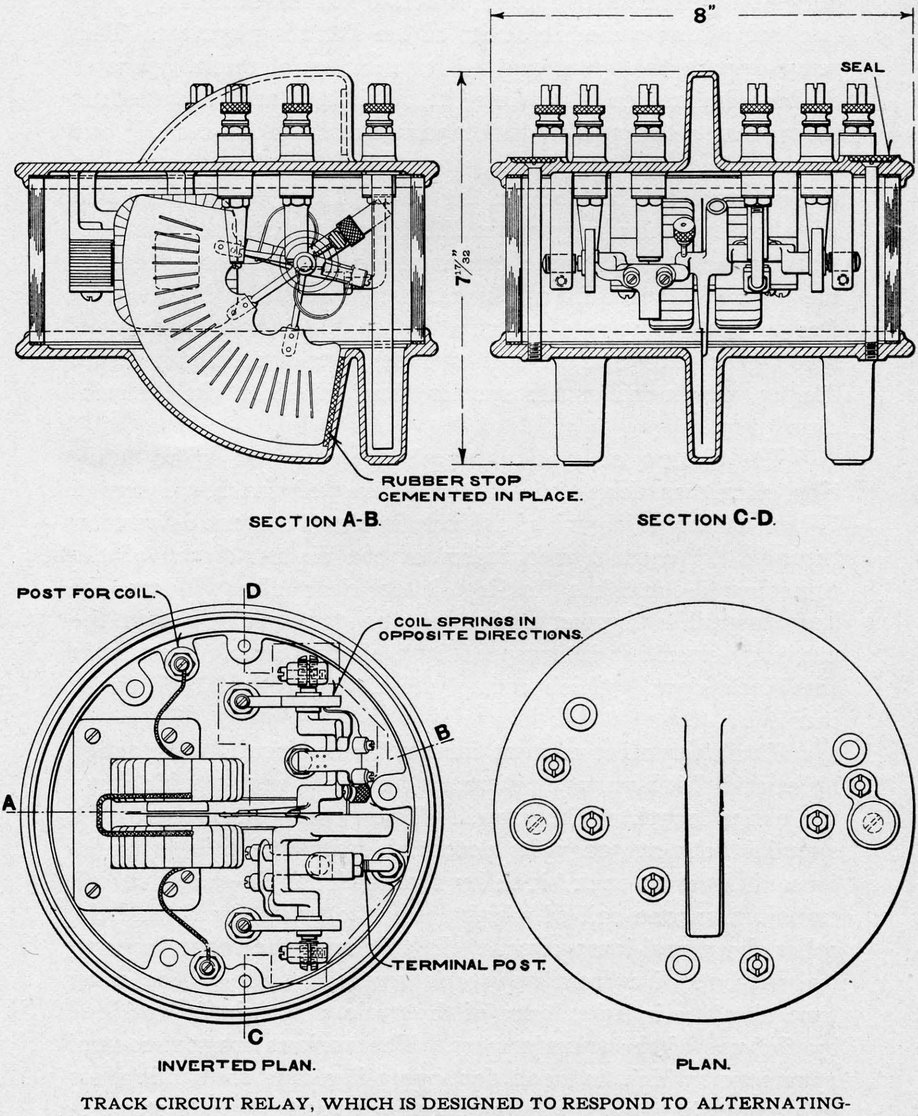


GENERAL VIEW OF ARRANGEMENT OF THE TRACK-CIRCUIT TRANSFORMER
THE INSTRUMENT CASE AND STOP-VALVE BOX, UPON A POST
IN ADVANCE OF THE BLOCK SIGNAL

signal-control apparatus being made from the opposite, or entering, end of the block, as shown in the wiring diagram on the opposite page. The track connections at the signal end of the block lead from the track circuit to the special alternating-current signal-control relay, which operates secondary connections in the various circuits of the signaling system. This relay apparatus, by means of its moving element, operates double contacts, so that when the block is clear and current is thus passing through it, two separate circuits are closed; one of these is the circuit leading to the automatic train stop at the entrance to the block in the rear. These magnets, which are thus operative only when the block is clear, actuate controlling air valves to the compressed-air cylinders operating the signals; the effect of the magnets becoming inoperative, due to the presence of a train in the block and consequent stoppage of the track-circuit current, is to set the signals to danger, which makes the system thus, in effect, the "normal clear" type.

The distant, or caution signals are operated by an auxiliary circuit as the result of the setting of the home signal. When the home signal of a block is clear, current is passing through the control mechanism of the distant signal of the preceding block, thus holding it at clear also. When the home signal is thrown to danger, the current flowing in the auxiliary circuit is interrupted by a special circuit breaker in the block signal, which causes the distant signal to indicate caution.

The alternating-current for the track circuits is supplied by special high-voltage alternating-current mains which run the entire length of the tunnel. These deliver current to the signal blocks at 500 volts potential, from which it is transformed down at each block by a special double-secondary oil transformer, one coil of which feeds the track circuit and the other the signal-lamp circuit. In this way the most economical method of current supply is secured, while at the same time absolute independence of the various circuits is obtained by the use of the transformers. The various magnet-control apparatus, which is used for operating the controlling air valves for the signal cylinders, receive current from a storage-battery main which also runs the length of the subway. This main is fed by several sets of 16-volt storage batteries in dupli-

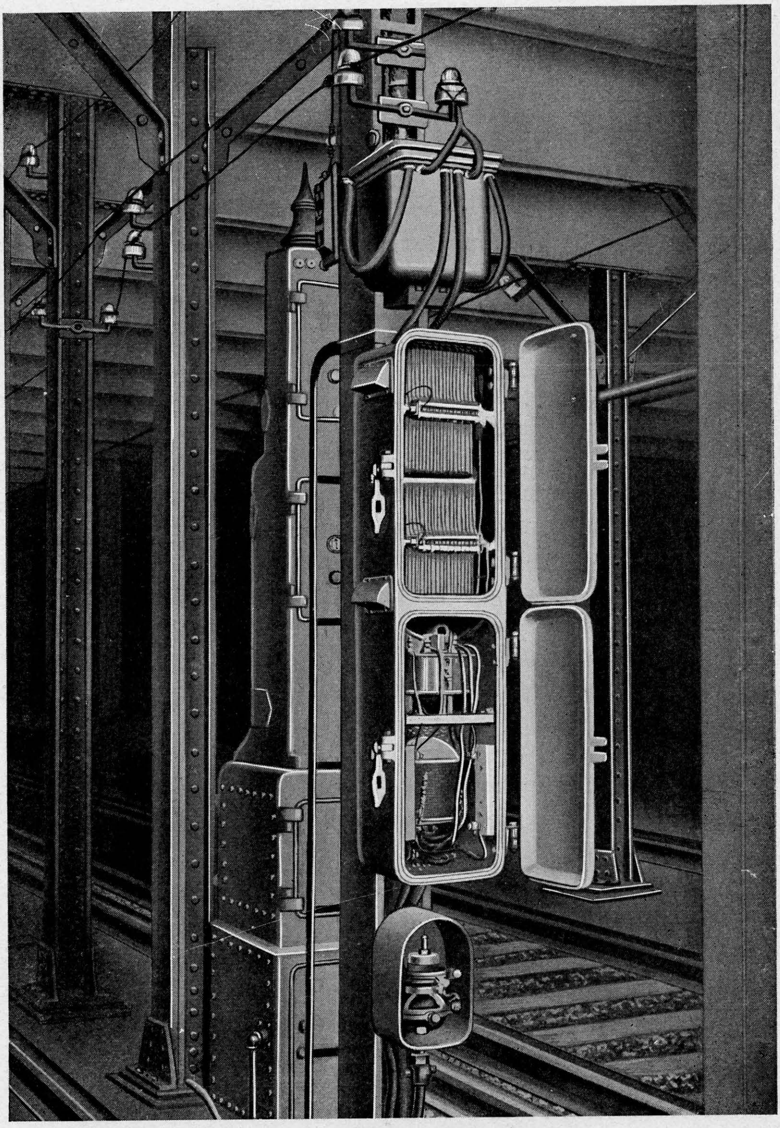


TRACK CIRCUIT RELAY, WHICH IS DESIGNED TO RESPOND TO ALTERNATING-CURRENT ONLY cate, which batteries are located at the various interlocking towers and are charged by motor generators.

The Signal Mechanism

On the opposite page is shown the arrangement of the apparatus installed at a block-signal station. As may be seen from the general arrangement of this apparatus in the tunnel, it consists of, first, the block signal and then a transformer, a case for the track-circuit instruments and the automatic stop-valve box. The purpose of the transformer has already been referred to; it takes current from the 500-volt main through 3-amp. enclosed fuses to the primary coil; its secondary contains two coils, one of which delivers current at 50 volts for use in the 4-cp incandescent lamps used in the signal, while the other coil delivers current at the lower voltage of 10 volts for use in the track circuit. As may be noted, the leads to the track circuits pass down the instrument case and thence to the rail connections at the exit end of the block; in the instrument case they pass through non-inductive resistances of 1 ohm, which serve to prevent any magnitude of current from flowing through these circuits in case of abnormal disturbing conditions in the propulsion-return current, and also prevent an excessive alternating-current passing from the transformer when short-circuited by the presence of a train in the track circuit which it feeds.

The details of the special transformer for supplying the current to the track circuits and also to the incandescent lamps used in the signals are simply worked out; it is an oil transformer of the usual type of construction, with the exception that it is equipped with two separate secondary windings. The primary winding is wound for the 500-volt alternating-current which is supplied from the mains leading through the tunnel while the secondary coil operating the track circuits is wound to deliver alternating-current at 10 volts, and the secondary coils supplying current to the signal lamps deliver current at 50 volts. These transformers embody the latest principles of transformer design and are very carefully insulated. A special grade of transformer oil is used, and the test voltage to which they are submitted before use consists of a "break-down" test of 5,000 volts between the primary and secondary coils and the core.



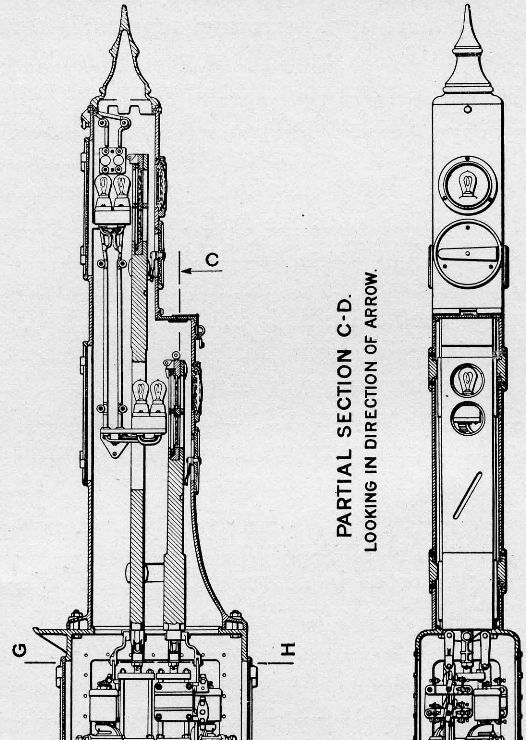
VIEW OF THE INSTRUMENT CASE IN ADVANCE OF THE BLOCK SIGNAL, WITH DOORS OPEN TO SHOW ARRANGEMENT OF RESISTANCE GRIDS, ALTERNATING-CURRENT TRACK RELAY AND ASSOCIATED APPARATUS

The special alternating-current relay is of an entirely new design and introduces an interesting departure from the preceding methods in signal work. The principle of operation involved is that of the action of an alternating-current field upon a slotted metallic (non-magnetic) vane, which is caused to move in such a way as to close the two circuit contacts. The alternating-current field is supplied by a magnet of laminated field-core construction, with the field coils arranged very close to the pole faces. The vane, which is of aluminum, is pivoted in a vertical position on jewel bearings. The effect of current passing through the field coils is that of causing the aluminum vane to rise to its upper position. Its general construction is well shown in the drawing on the opposite page.

The alternating-current relay and associated apparatus are housed in a neat and compact cast-iron instrument case of water-tight construction, as shown on page 18. This consists of two sections, the lower part containing the relay and connections, and the upper part the grid resistances, which are, as above stated, connected in series with the circuits supplying alternating current to the track circuits, and that of the connections between the tracks and the relay. These cases are secured to steel posts in the subway directly in advance of each signal, as shown on the opposite page. The wiring arrangements in these instrument cases are very carefully provided for; outlets for cables are provided for, and all the wiring is through cables as thus arranged. A seven-conductor cable leads to the signal nearby, while another seven-conductor cable leads to a junction box of the signal wiring nearby, from which connections are made to the distant signal mechanism in the preceding block and to the automatic stop, as well as to the storage-battery mains for the direct-current supply for the signal mechanism. Four conductors lead out to make the necessary connections with the rails on either side of the insulating section.

The Signals

The small amount of space available in the subway portion of the system made it necessary to design a special type of signal involving radically new features. Clearances would not permit of a "position" signal indication, and, further, a position signal purely was not suitable for the lighting condi-



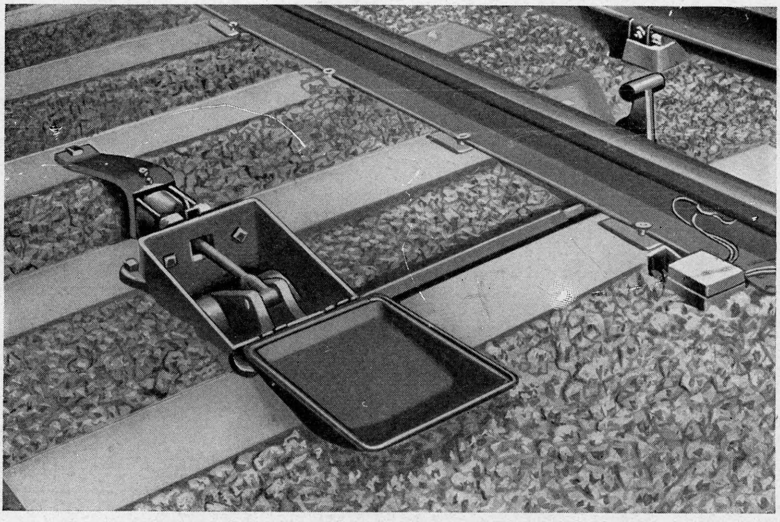
STANDARD SUBWAY BLOCK SIGNAL, SHOWING ARRANGEMENT OF MECHANISM AND THE ACTUATING VALVES FOR CHANGING THE COLOR INDICATIONS

tions of the subway. A color signal was therefore adopted, conforming to the adopted rules of the American Railway Association. It consists of a vertical iron case fitted with two white lenses, the upper being the home signal and the lower the distant. Suitable colored glasses are mounted in slides, which are operated by pneumatic cylinders placed in the base of the case. Home and dwarf signals show a red light for the danger or "stop" indication. Distant signals show a yellow light for the "caution" indication. All signals show a green light for the "proceed" or clear position. The design of signal finally adopted is illustrated upon page 20.

Although the limitations of space prohibited the use of semaphore arms or similar means of position indication, a position indication has, however, been provided for, as an auxiliary to the color indications, in the form of the small arm immediately beneath the lenses. A small blade appears in a horizontal position when a danger or caution signal is displayed, and at an inclination of 60 degs. when safety is displayed, this being provided in addition to the color indications for use in case of failure of the lamps for the color indications.

The signal consists of two sections; the upper and rear portion contains the lenses and position indicator for the home signal, the colored glasses showing red for the danger or stop position, and green for the proceed or clear position. The front and lower portion of the case contains the distant signal mechanism, which is arranged to show yellow for the caution indication and green for the clear position. Thus it may be seen that color indications are depended upon, the position indication, which is provided by the small blade under each lense, being added merely as a tell-tale. Each lense is constantly lighted by two 4-cp incandescent lamps at the rear, the two lamps being connected in parallel for a safeguard in order that one may be always lighted even if the other burns out; in this way the lighting is made as nearly absolutely reliable as possible. These lamp circuits are, as above stated, operated from the local block transformers, the special double coils delivering 50 volts, alternating-current, for this purpose.

The mechanism of the signal is clearly shown in the plate on the opposite page. The pneumatic cylinders, which operate the heavy vertical sliding frames carrying the color lenses for the signal indications, are located in the base portion of the case. As may be seen, the controlling magnets for the air valves of both the home and the distant signal cylinder mechanism are located conveniently for access, as are also the various portions of the cylinders and slides. It should be here noted that the slides exhibit the green color for the "clear" or proceed indication only when held in its upper position by the pneumatic cylinder; in this way any accident to the apparatus, cutting off the compressed air, will permit the heavy slides to drop and indicate the red color for "danger." The details of the lamp arrangements, wiring, and the method of operating the small blade position indicator, are also clearly shown on the opposite page. This blade has a crank extending within the case and ending in a pin which plays in an inclined groove in such a way as to turn the blade through an angle of 60 degs. as it passes from upper to lower position.



THE MACHANISM FOR OPERATION OF THE PNEUMATIC TRACK TRAIN STOP, SHOWING TRIGGER ELEVATED TO "STOP" POSITION

The signals which are used on the exterior elevated portions of the system are of the position indication type, although operated similarly to those in the subway sections and by a similar construction of mechanism; the position indication of semaphore arms, which is depended upon in the main, is suplemented by the color system for night work. The design of the signal of this type differs little from the subway type; the base portion of these signals is identical with that used for the tunnel signals, and the two pneumatic cylinders and their magnet controlling valves are similar, but in this case the cylinders operate semaphore arms instead of the heavy sliding frames. In these signals the color indications for night purposes are provided by incandescent lamps, also in duplicate, which burn continuously. These lamps are located in a specially designed water-proof case. Their current supply is also taken from the local block transformers of the block system, and are thus independent of the power and general lighting circuits of the subway system.

Automatic Train Stop

A train stop or automatic stop is used at all block signals, and at many interlocking signals. This device automatically applies the air brakes to the train if it should pass a signal in the stop position, being an additional safeguard only to be brought into action when the danger indication has for any reason been disregarded; it insures the maintenance of the minimum distance between trains as provided by the overlaps established.

The automatic train stop consists of a trip located at the side of the running rail, which is normally raised to such a position that it will come in contact with the special brake valve arrangement upon the trucks of each subway car and throw the air brakes to full emergency in case the train attempts to pass the stop. This trip is operated by a pneumatic cylinder located in a closed box between the ties and the middle of the track opposite. The arrangement of this stop in relation to the block signal is illustrated on page 14. The controlling wires for the stop, and the compressed air connections to its cylinder, are also clearly shown in this view.

The operation of this automatic stop coincides with that of the home signal in the block next preceding it. When that home signal indicates danger, the trip is in its elevated position, so as to make an emergency application of the brakes. This trip is normally held in its elevated position by a heavy counter-weight located within the controlling box in the middle of the track as shown on the opposite page. When the home signal is cleared,

VIEW OF THE AIR-BRAKE VALVE UPON THE TRUCK BENEATH THE CAR, WHICH IS OPENED IF TRAIN ATTEMPTS TO RUN PAST TRAIN STOP compressed air is admitted also to the pneumatic cylinder of this automatic stop, which acts to raise the counterweight and thus lower the trip, holding it depressed until the home signal is again changed to danger indication.

The controlling mechanism for the automatic stop is located in a neat cast-iron box upon the pillar below the track-instrument case illustrated on page 18. The mechanism consists of a magnetically operated air valve of the same type as used in the signals, which is so connected as to be operated in conjunction with the home signal, as above mentioned. Thus, when the home signal is set to "clear," the automatic stop valve is also operated to admit compressed air to the pneumatic cylinder, which depresses the trip. An additional feature of interest involved in this controlling box is to be seen in the form of an automatic stop release, by which, in case of failure of any portion of the signal control, the automatic stop can easily be depressed to "clear," so that a train may proceed without danger of an emergency application of the brakes. This is accomplished by a special key, which the guard or conductor may insert in the controlling box and turn to admit air to the pneumatic cylinder; as long as he holds the key turned the trip remains depressed, and as soon as the key is removed the trip will normally rise again. This ingenious mechanism adds an important factor of safety to train operation in the subway.

Special Safety Devices

Two novel safety devices closely allied with the signaling system may be here described. The first is an emergency train stop for the use of those at stations. It is designed to place in the hands of station attendants, or others, the emergency control of signals upon all adjacent approaching tracks. The protection afforded is similar in principle to the emergency brake handle found in all passenger cars, but operates to warn all trains of an extraneous danger condition.

It has been shown in electric railroading that an accident to apparatus, perhaps of slight moment, may cause an unreasoning panic, on account of which passengers may wander on adjoining tracks in face of approaching trains; on a four-track railway, with express trains approaching at high rates of speed so as not to receive visual warning in time to stop, this is especially hazardous. Other conditions also may develop, such as a passenger being forced off a station platform, injury to a workman, etc., thus rendering an emergency control of trains very desirable. To provide as perfectly as practicable for such conditions, it has been arranged to loop the control of signals into an emergency box set in a conspicuous position in each station platform. The pushing of a button on this box, similar to that of the fire alarm signal, will set all signals immediately adjacent to stations in the face of trains approaching, so that all traffic may be stopped until the danger condition is removed.

The second safety appliance is the "section break" and cross-over protection. This consists of a special emergency signal placed in advance of each separate section of the third rail; that is, at points where trains move from a section fed by one sub-station to that fed by another. Under such conditions the contact shoes of the train temporarily span the break in the third rail. In case of a serious overload or ground on one section, the train wiring would momentarily act as a feeder for the section, and thus possibly blow the train fuses and cause serious delay until they could be replaced.

In order, therefore, to prevent trains passing from a section charged with the full normal potential into a dangerously over-loaded or grounded section, an overload relay has been installed at each section break to set a "stop" signal in the face of an approaching train, which holds the train until the abnormal condition is removed. The apparatus is applied at all section breaks in the third-rail and at all cross-overs where the train might pass from a third-rail section in one track to a different one on another track. In any of these cases serious trouble might occur from one third-rail section being grounded while an adjacent one is at its full voltage.

On express-line tracks an effect of this signaling mechanism will be to throw the home signal to danger at the nearest block in advance of the third-rail section break. The method of operation of this signal control mechanism is interesting; it consists of a differential magnetic mechanism with rotating armature, one of the magnetic coils being connected between the third rail and the ground on one side of the section break, and the other magnetic coil similarly between the third rail and the ground on the other side of the break.

When both sections of the third rail are fully charged, these magnets operate so as to annul each other, so that the rotating armature is not attracted; if, however, the current supply is removed from either section of the third rail, one of these magnetic coils becomes inoperative, while the other is still magnetized, and the result is that the differential action is removed and the armature is strongly attracted and, by lifting a counter-weight, breaks the contact in the control circuit of the nearest home signal in advance of this point. This sets the home signal to danger, and in turn the distant signal at the further block in advance, to prevent trains from approaching the section under these circumstances.

Upon the local tracks, where a block signal is not used, a special type of section-break signal will be used for a similar purpose and prevent trains from approaching a section break when voltages are unequal on either side. This type of signal is operated by a differential relay of special construction and gives a color indication. In this case a warning of approaching trains is furnished by a special box plainly marked "S. B.," which indicates by a red light for danger or stop.

At cross-overs and sidings, where it is similarly desired to prevent trains from crossing over from one third-rail section to another in case of unequal voltages upon the third-rail sections, a different procedure is necessary. In these cases a special form of indication is to be used, which will show the tower man, or those in charge of the interlocking switches, whether it is safe for trains to be passed over from one section to another or not. This will be accomplished by means of vertical scale voltmeters arranged side by side and connected to the third-rail sections on either side of the cross-over; by a mere glance at the voltmeters, the switchman can easily see whether the voltages on both sides are sufficiently near together to permit trains to cross over safely.

There has also been installed a special emergency signal system, embodying provision for cutting off power from the contact rail, in case of imminent danger. In the booth of each ticket seller and at every manhole along the west side of the subway and its branches is placed a glass-covered box of the kind generally used in large American cities for fire alarm purposes. In case of accident in the subway which may render it desirable to cut off power from the contact rails, this result can be accomplished by breaking the glass front of the emergency box and pulling the hook provided. Special emergency circuits are so arranged that pulling the hook will instantly open all the circuit breakers at adjacent sub-stations through which the contact rails in the section affected receive their suply of power. It will also instantly report the location of the trouble, annunciator gongs being located in the sub-stations from which power is supplied to the section, in the train despatchers' offices and in the office of the general superintendent, instantly indicating the number of the box which has been pulled. Automatic recording devices in train despatchers' offices and in the office of the general superintendent also note the number of the box pulled.

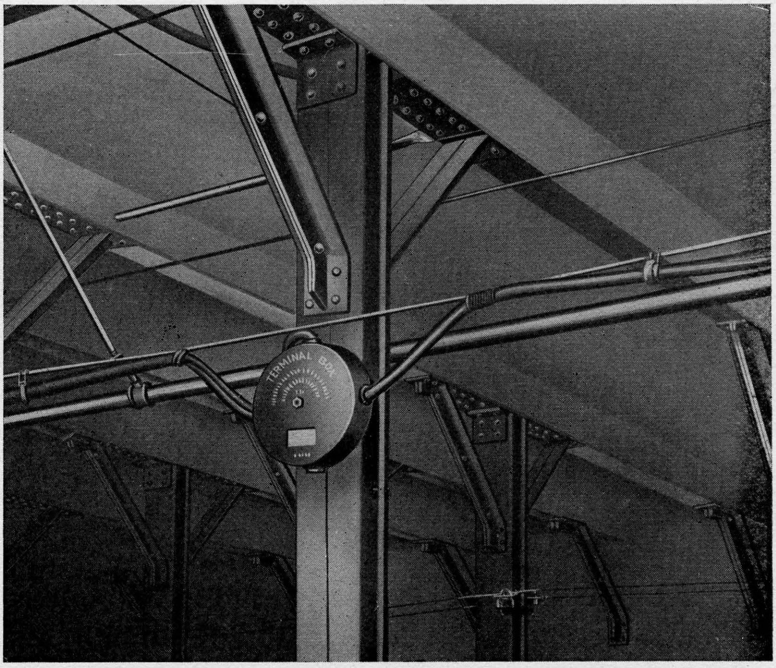
The provision of such elaborate means for protecting trains and insuring safety to workmen in the tunnel is a remarkable testimony of the completeness of the work of installation, and will insure the confidence of the traveling public.

The Electric Current and Compressed Air Supplies

An important feature of the signal and interlocking work is the provision of supply for the 500-volt alternating-current distribution mains throughout the subway system and for the low-voltage direct-current storage-battery supply mains, extending to all signals throughout the system for operating the valve controlling magnets, and also for the compressed-air supply system. The alternating-current main is fed by seven motor generators, arranged to operate in multiple, each of which is of 30 kw capacity, generating single phase, alternating-current at 60 cycles and 500 volts. They are located separately in seven of the more important sub-stations of the line, so that it will be practically impossible that all should be disabled at the same time, thus affording an important factor of safety to the system, inasmuch as any four of these machines will deliver the current required for operating the entire system. The various machines operated will feed into the main in multiple from its point of location upon the system.

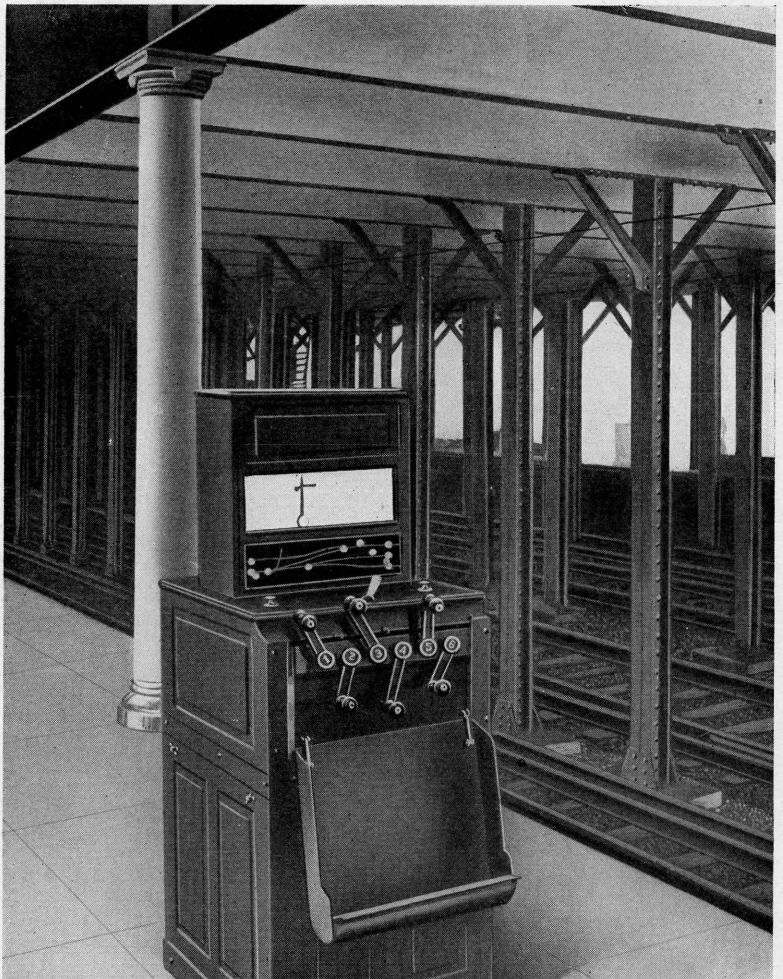
The direct-current main, supplying current for the signal operating magnets, is supplied by eight groups of storage-battery sets in duplicate, each set designed to deliver 16 volts, located at convenient points in the subway, usually in signal towers. Each battery has a capacity of 450-amp.-hours, and the two sets at each battery station are operated alternately, one being charged while the other is discharging. The batteries are charged by small motor generators, driven by current from the 600-volt direct-current propulsion system, one being located at each storage-battery point. They deliver to the storage batteries at 25 volts potential.

The compressed-air supply for the various signal mechanisms and switches, the automatic car stop, etc., is supplied by a 2-in. main extending the length of the system. This main is fed by six 35-hp electrically-driven compound air-compressors, one of which is located in each of the following sub-stations: Nos. 11, 12, 13, 14, 16 and 17; three of these are reserve units. These are driven by Westinghouse direct-current motors, taking current from the direct-current bus-bars at the sub-stations at from 400 volts to 700 volts. These compressors have each a capacity of



ARRANGEMENT OF AIR-SUPPLY PIPING AND CONDUIT SYSTEM IN THE SUBWAY, TO CARRY THE SIGNAL CIRCUIT WIRES

230 cu. ft. of free air per minute, delivered into the supply system at a pressure of from 60 lbs. to 75 lbs. per square inch. These compressors are each automatically controlled, in an interesting manner, by the rise or fall of air pressure in the system. The details of this controlling apparatus are interestingly worked out. A pressure gage operating upon the Bourdon steam gage principle is arranged to make different contacts for certain maxi-



A TYPICAL ELECTRO-PNEUMATIC INTERLOCKING MACHINE LOCATED UPON A STATION PLATFORM, FOR THE OPERATION OF CROSS-OVER SWITCHES mum and minimum pressures, as shown upon the switchboard. When the pressure falls so as to close the upper contact, current is delivered to an automatic switch, which operates a mechanism in such a way as to move the starting resistance switch for the air-compressor driving motor. This mechanism is so arranged that when the starting resistance is cut entirely out and the motor is up to speed, the starting switch is held magnetically in place, and the solenoid is actuated so as to throw the load onto the compressor to cause it to deliver air to the system. This same action starts the flow of cooling water through the cylinder jackets of the compressor cylinder, and automatically admits oil to the cylinders and bearings. When the air pressure in the system rises to the predetermined maximum the opposite contact is made, which causes the load to be removed from the compressor by closing the delivery of the system, and also shuts down the motor, the jacket water supply for the compressor and the oiling system being also incidentally shut off. In this way the compressor is always started unloaded and stopped unloaded, the action being entirely automatic, so that no attention is required; it is designed to respond to variations of air pressure of 5 lbs. or less, and operates very satisfactorily.

The Interlocking System

The to-and-fro movement of a dense traffic on a four-track railway requires a large amount of switching, especially when each movement is complicated by junctions of two or more lines. Practically every problem of trunk-line train movement, including two, three and four-track operation, had to be provided for in the switching plants of the subway. Further, the problem was complicated by the restricted clearances and vision attendant upon tunnel construction. It was essential that the utmost flexibility of operation should be provided for, and also that every movement be certain, quick and safe.

All of the above, which are referred to in the briefest terms only, demanded that all switching movements should be made through the medium of power-operation interlocking plants. These plants in the subway portions of the line are in all cases the Westinghouse electro-pneumatic, while in the elevated portion of the line mechanical interlocking has been in some cases provided.

Special equipments of both interlocking signals and switches were designed with particular reference to the subway installation requirements, and in it is involved a most interesting study of modern interlocking. Provisions have been made for handling the maximum of traffic conditions without congestion at yards and switching terminals.

A list of the separate and distinct interlocking plants which have been installed in the subway will be interesting, and are accordingly given herewith:

Main Lines

Location.	Interlocking Machines.	Working Levers.
City Hall	3	32
Spring Street	2	10
Fourteenth Street	2	16
Eighteenth Street	1	4
Forty-Second Street	2	15
Seventy-Second Street	2	15
Ninety-Sixth Street	2	19

West Side Branch

100th Street	1	6
103d Street	1	6
110th Street	2	12
116th Street	2	12
Manhattan Viaduct	1	12
137th Street	2	17
145th Street	2	19
Dyckman Street	1	12
216th Street	1	14

East Side Branch

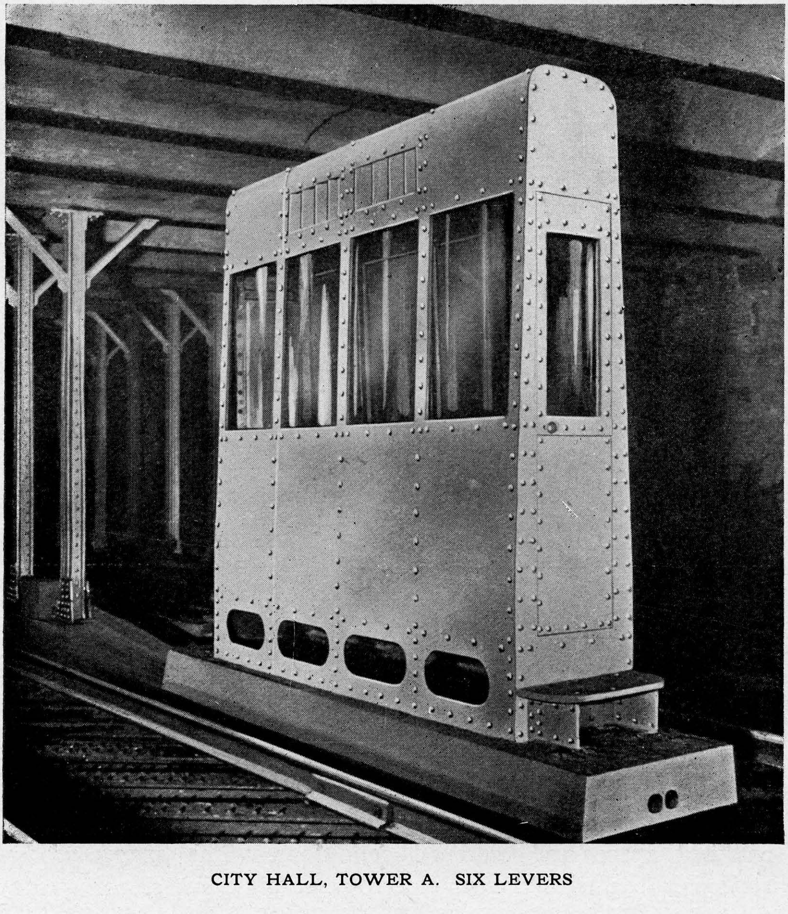
135th Street	2	6
Lenox Junction	1	7
145th Street	1	9
Lenox Avenue Yard	1	35
Third and Westchester Ave. Junction	1	13
St. Ann's Avenue	1	24
Freeman Street	1	12
176th Street	2	66
Total	37	393

Total number of switches............................224

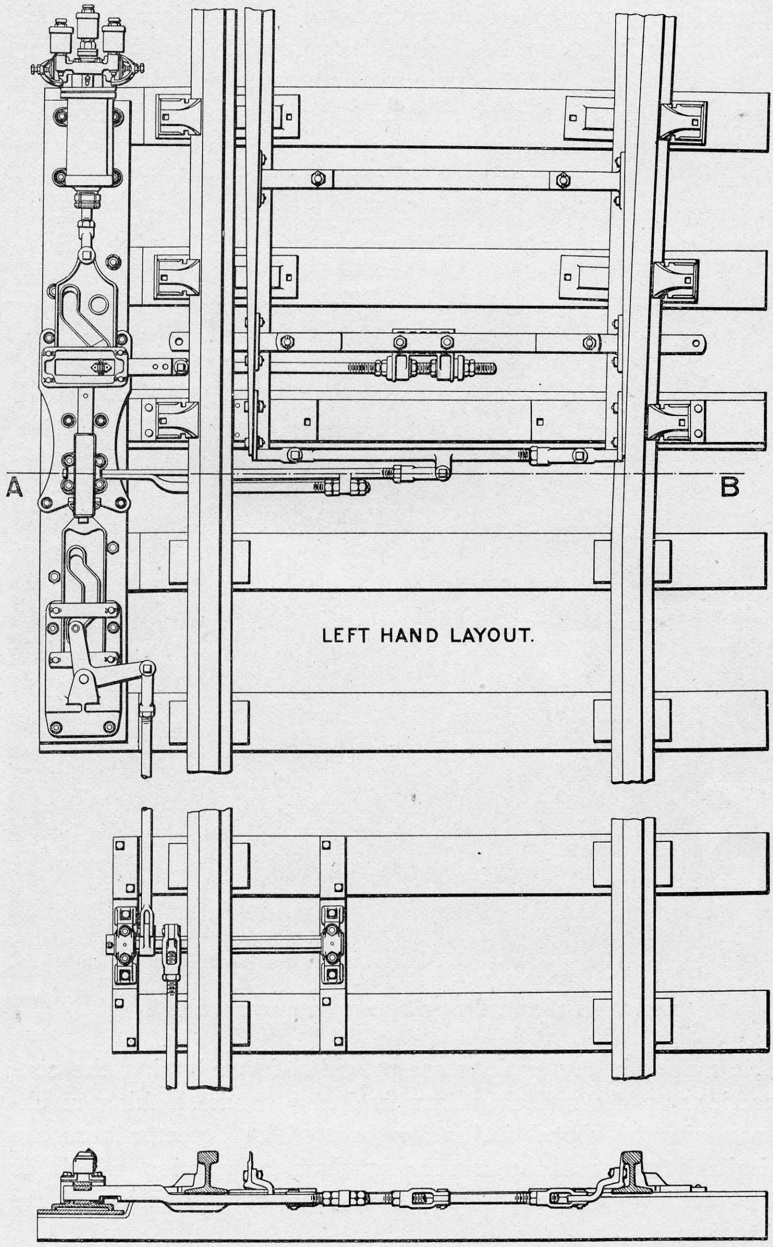
The total number of signals, both block and interlocking, is as follows:

Home signals	366
Dwarf signals	150
Distant signals	193
Total	709

It will be noted that in the case of the City Hall station three separate plants are required, all of considerable size, and intended for constant use for a multiplicity of train movements. It is, perhaps, unnecessary to state that all the mechanism of these important interlocking plants is of the most substantial character and provided with all the necessary safety appliances and means of rapidly setting up the various combinations. The interlocking machines are housed in steel concrete "towers," so that the operators may be properly protected and isolated in the performance of their duties. An unusual type of switch movements and interlocking mechanism is required in the subway installation on account of the confined space and cramped conditions. The apparatus installed is the well-known electro-pneumatic interlocking system of the Union Switch & Signal Company, but the form of apparatus used is of an entirely new and radical design. The pneumatic switch operating movements are arranged with the pneumatic cylinders and the movements at the side of and below the top of the rails. A general idea of the arrangement of this new type of switch movement may be gained from the

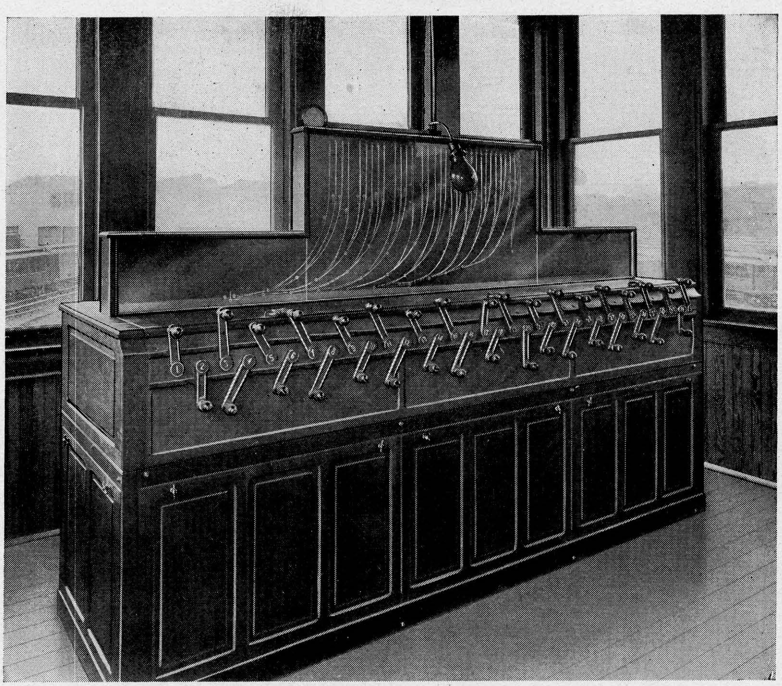


CITY HALL, TOWER A. SIX LEVERS



SECTION THROUGH A-B.

S & L AND DETECTOR BAR MOVEMENT APPLIED TO A NON-INSULATED SINGLE SWITCH ONE DETECTOR BAR AHEAD OF POINT drawing on page 34. Innovations are to be found in this mechanism in the application of the cam plate for the shifting of the switch and of the arrangement of the switch indication box. The magnetically controlled valves for operating the pneumatic cylinders, as well as also the switch tower apparatus used in connection with these apparatus involves nothing new in design. The cylinder has a stroke of 8 ins. in operating the cam plate which moves the switch points. Suitable magnetic connections are provided for adjusting the connections to the switch points, and also to the locking mechanism in the signal indication box. The detector bars are similarly operated by a rocking shaft connection which is traversed by a separate cam plate, as is clearly shown in the drawing.



LENOX AVENUE YARD MACHINE. THIRTY-FIVE LEVERS

In the Lenox Avenue yard, space at the side of the track is so narrow and the arrangement of switch leads to the car house are so complicated as to prevent the location of the switch operating cylinders at the sides of the track, so that a new design of centrally-located cylinder was prepared for this particular location. In this case the cylinder has a through piston rod, with stuffing boxes in each head, and operates the switch by acting against two bent plates. Adjusting knobs are located at each end of the piston rod, so that the stroke of the switch cylinder may be easily adjusted to the movement of the switch.

The magnetically controlled air valves are in this case located in the narrow space between the third rail and the retaining wall at one side. In all features of the switch construction, however, careful provision has been made for ease of inspection and repairs, so that the expense of maintenance will be reduced to a minimum, while reliability of operation will be insured.