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AUTOMATIC TRAIN CONTROL
THESIS FOR DEGREE OF B. S.

F. I. PHIPPENY

1926

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AUTOMATIC TRAIN CONTROL

A Thesis Submitted to the

Faculty of the

MICHIGAN STATE COLLEGE

by

F. I. Phippeny

Candidate for the Degree of

Bachelor of Science.

June 7, 1926

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AUTOMATIC TRAIN CONTROL.

SYNOPSIS: * The paper gives a very brief outline of the history of train control in the United States for the last four years; a summarization of what automatic train control is intended to accomplish; being intended as an adjunct to manual control. Train control may be used to regulate speed, limit speed or entirely stop rolling stock depending the local conditions or it may do all of these things. It must not interfere with manual control in any way. The purpose of this paper was to review briefly what had been accomplished in the field, make suggestions as to most desirable system to use/^{and}part of the thesis consisted in constructing a workable model and demonstrating it to the public as a means of furthering education along this line, with final result that popular demand will force installation of automatic train control on all large public carriers.

DEFINITION: Automatic train control is the name applied to any device that electrically or mechanically either reduces, controls the speed of, or brings a locomotive and it's load to a stop due to predetermined combinations of the right of way over which the locomotive is moving. This all being accomplished without intervention by the train crew.

* This thesis has been worked up with the great assistance of E.L.Rayner, '22, which is hereby gladly acknowledged

HISTORICAL: January 10^{*}, 1922, the Interstate Commerce Commission issued an order requiring all railroads having in operation automatic signalling systems to investigate and cause to be installed on test sections of tract devices for automatically transmitting the indicated tract signals to the cab and braking equipment of a locomotive moving through the block. This order probably was issued as a result of several costly accidents due to the failure of trainmen from one cause or another either to see or correctly interpret visual signals. In two or three cases the locomotive engineer was found dead at his post in sufficient time to prevent serious consequences. As a result of this order organized investigation of Automatic Train Control was initiated in all parts of the country. The following chart will give an idea of the spread of the work during the first two years after the order was issued.

System	Miles installed	Kind	Year
C.R.I.&P.	165	Int and cont imp.	1923
C.N.&W.	12	" ind "	"
M.P.P.	15	" " "	"
St.&S.F.	5.8	" " "	"
U.P.	10	Various	"
A.T.&S.F.	47.4	Cont induction	1924

* I.C.C. order 13,413 Jan 10, 1922

the first of these is the fact that the system is not a simple one, but a complex one, in which the various parts are interrelated and interdependent. The second is that the system is not a static one, but a dynamic one, in which the various parts are constantly changing and evolving. The third is that the system is not a closed one, but an open one, in which the various parts are constantly interacting with the environment. The fourth is that the system is not a linear one, but a non-linear one, in which the various parts are constantly interacting with each other in a non-linear fashion. The fifth is that the system is not a deterministic one, but a probabilistic one, in which the various parts are constantly interacting with each other in a probabilistic fashion. The sixth is that the system is not a simple one, but a complex one, in which the various parts are interrelated and interdependent. The seventh is that the system is not a static one, but a dynamic one, in which the various parts are constantly changing and evolving. The eighth is that the system is not a closed one, but an open one, in which the various parts are constantly interacting with the environment. The ninth is that the system is not a linear one, but a non-linear one, in which the various parts are constantly interacting with each other in a non-linear fashion. The tenth is that the system is not a deterministic one, but a probabilistic one, in which the various parts are constantly interacting with each other in a probabilistic fashion.

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System	Mileage	Kind		Year
B.&O.	8.2	Int Inductive		1924
N.Y., N.H.&H.	10.5	Cont.	"	"
N.&W.	106	"	"	"
P.&R.	54	"	"	"
StL.-S.F.	5	Int.	"	"
S.P.	49.6	"	"	"
U.P.	107	"	"	1925
O.W.R.&N.Co.	85	Cont.	"	"

But the list begins to lengthen and the mileages increase from this time on. The things this little chart show are the wide area over which such installations are being made and the preference that is being shown for two types which will be described more in detail later.

The different manufacturers of railway signal apparatus were ready at the time the I.C.C. Order was issued with apparatus for immediate^{installation}; in all cases it being designed to become an adjunct of the visual systems then in use. The fact that such apparatus was reaching a stage of development where it was reliable enough to warrant its installation for test purposes at least may have been one of the contributory reasons for the Order of January 1922. As might be expected the early apparatus lacked the refinement of contact with actual operating conditions and it was not until in the first part of the past year that the field began to install different fundamental systems which were uniformly reliable.

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If it was within the scope of this paper, a volume can be written on the requirements and limitations and controlling conditions for a satisfactory automatic train control, but that this report may be as brief as possible with clearness we will content ourselves with the following summarization.

SUMMARIZATION OF THE FUNCTIONS OF AUTOMATIC TRAIN CONTROL:

Automatic Train Control as defined earlier in the paper must interfere as little as possible with the work of the locomotive engineer and yet must perform his task in case he fails or is slow in acting or acts wrongly. It has as it's functions; the limiting of speed, maintaining of speed and the stopping of rolling stock. It may perform any or all of these things depending upon the demands made in particular instances. It must be extremely dependable fairly simple and not too expensive to install and maintain. While automatic apparatus must be capable of doing all the things enumerated it first of all must not interfere with the operator if he is proceeding logically. To the present time apparatus has been designed that makes continuous contact with the locomotive by maintaining an alternating impulse between the rails which is picked up by sensitive coils on the locomotive, apparatus that receives an impulse from "inductors" located along the right of way and still the third arrangement is to make a direct contact with the

locomotive thru ramps at intervals along the track. This arrangement has been in use for a long time on interurban electric roads for signalling from and to the trains. This right of way apparatus is called the transmitter, the apparatus on the locomotive for receiving the reaction from the track being called a receiver. The receiver may be a set of coils located on an open cored transformer the legs of which project downward in such a manner that as they pass over a trackside inductor the reluctance of the magnetic path is changed. This arrangement enables all power supply to be located on the rolling stock. Another receiver is a multiturned coil located on some cross member of the engine frame which picks up an alternating impulse continuously from the track. This impulse has to be enormously amplified by vacuum tube amplifiers as the relative amount of flux passing thru such a coil is a very small amount of the total flux passing thru all cross parts of a heavy train. In addition to transmitter and receiver, control apparatus must receive impulses, either open or closed circuits from the present signal system. On the locomotive and tender are located relays, power supply visual signals for the operators and electro pneumatic valves for controlling the braking apparatus. It appears as though the main problem is that of infallible connection between the train and the right of way. The design of satisfactory

the first of these is the fact that the system is not a closed system.

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auxiliary apparatus is one that the engineering department of the signal companies should be able meet in a satisfactory manner. In view of the foregoing we believe that eventually the use of ramps will be universal and as a result in setting up a working model this arrangement was used.

OPERATION OF THE MODEL: This thesis work was decided upon several weeks before the annual electrical show and we determined if possible to exhibit a model at the show. As has been stated previously, the use of ramps for communicating impulses to and from the trains appeared to us to be the best method and accordingly we devised a circuit including the necessary relays for the operation of a model. (See diagram # 1) As is always the case, between the decision to do a thing and the accomplishment of the finished product, there elapses a period of experimentation and many points caused considerable trouble. All doubtless due to unfamiliarity with the particular field but perhaps such overcoming of obstacles might have been necessary no matter who attempted the problem. Perhaps such an expenditure of time and effort was not justified in view of the fact that several operative systems were already in use but again I stress the fact that we desired an unbiased understanding of the whole problem and this could only be

arrived at through independent effort. Also, even the construction of a model demanded the solution of it's own problems which were unlike those to be expected under other conditions. The model was completed in time for the show and was exhibited satisfactorily by members of the electrical student body during the whole show. A photograph is attached.

In actual operation of trains an infinite number of combinations may arise, such as two trains approaching each other along the same track, one catching up with the other, trains approaching a crossing, etc. It became necessary for us to assume some condition and work it out as an illustration of the operation of the train control idea. We assumed a single track on which trains were moving one behind the other in both directions. The simplest case being that of two blocks tied end to end and a train moving both directions over them. This accomplishes two things, "Saturates" the blocks both ways and is one of the hardest problems in traffic moving that is met by the dispatcher. In order to pass the trains two switches had to be included and also means for controlling the motion of the trains into and back out of these sidings after passage of a train in the opposite direction. This perhaps is a step beyond the requirements of train control but it is apparent it is a reasonable

application of control. For convenience we mounted the relays along right of way. These relay controls might be assumed to correspond to the complicated relay arrangement in the present types of visual signal systems. (At this point see diagram # 1 again) We used electric locomotives and went one step further than the usual application of control in that we shut off the power supply to the locomotive and did not attempt to brake them with one exception in which regenerative braking was used.

A great many people saw the model operate but a description of the sequence of operations is necessary at this point. Consider a train to be moving thru a block and it comes to another block in which control operates on it for some reason. (In case of model because of another train already in block and approaching the first train) The effect of automatic control in this case was to slow the train down and put it into the siding in the clear. If this occurred before the approaching train was within limit of control, the control would not operate on the approaching train which passed right on by. The first train then had to back out of siding onto main line, stop and proceed ahead on it's schedule. Necessary operations to be performed by automatic control were opening of switch for train to side, closing switch to allow approaching train to pass, again opening switch for first train to back out onto line, again closing switch for train to proceed, stopping and reversing trains.

The actual operations that were performed have no particular bearing on our problem as what was done by the control is a secondary matter. Our problem was to demonstrate in a clear fashion that such control is possible and desirable. The model used third rail power supply and the motors were shut down by opening this circuit where ever necessary.

OPERATION OF INTERMITTENT INDUCTIVE SYSTEM: The arrangement for this system was briefly mentioned earlier in the paper but there is here included a brief description of such a system. The means by which control is transmitted from the roadway to the moving train is induction, employing the inductor alternator principle as show in diagram # 2.

The inductor G is fixed on the ends of the ties with the ends of the pole faces $2\frac{1}{2}$ " above the top of the running rails. The receiver or locomotive element A is carried on the tender truck so that it's faces pass about two inches above the pole faces of the inductor. On one leg of the receiver is placed a primary coil D fed from a storage battery. A secondary coil E on the other leg of the receiver includes in it's circuit a storage battery and a relay H. The magnetic flux in the secondary coil remaining constant in amount, keeps the flow of current thru the relay likewise constant and holds the relay contacts closed. This is the normal condition of the locomotive. When, however, it passes a control point, if the circuit of the choke coil G is open, the inductor, partially completing the magnetic circuit of the receiver, will cause a large change of mag-

magnetic flux within coil E, which in turn will result in a sufficient change of current to open the relay. The relay, when open, causes a brake application. If, as the locomotive passes, the circuit of coil G is closed (by the track relay of the section to which this control applies) this coil will then act as a choke, preventing the magnetic flux from varying materially in the secondary coil of the receiver; the engine relay will not be opened and the train will not be stopped.

The only thing necessary to make the inductor effective is the opening of the track circuit. This arrangement avoids all trouble or expense of maintaining a roadside battery for train control purposes. The receiver is fitted in between the projecting springs and journal box of the truck frame of the tender. It is adjustable for wear. The relays on the engine are so housed and mounted as to be immune to the effects of vibration. They have very light short armatures mounted on jeweled bearings. Two relays are employed, a primary and a secondary. The primary relay, designed to be especially rapid in action, takes a very small amount of energy. The secondary relay need not be rapid in action and is provided with heavy carbon to metal contacts, giving a wide break and is capable of continuous and satisfactory handling of the current taken by the electro-pneumatic valve. They are so housed that they are protected from frost and dust.

The brake setting apparatus consists of an electro-pneumatic valve, controlling a cylinder which is directly connected to the engineers brake valve handle with a mech-

anism designed that the valve will move to the service

position without danger of jumping to the emergency position. The engineer may at any time put on the emergency if he so desires; or, by exerting heavy pressure against the brake handle, he can modify an automatic brake application.

Absence of air permits a heavy spring to move the brake handle to the service position.

The apparatus is so designed that the engineman who permits automatic application of the brakes can release them only after the train has stopped. The reset key, with front and back contacts, is fixed on the side of the tender midway between the front and back end, and is so connected in the circuit that if operated following an automatic application of the brakes, it will restore the automatic equipment to normal.

In order to set up the proper combination so that the engine will not be under control when operating against the current of traffic, a reversing switch is employed, and arranged to be operated by one of the axles of the locomotive or tender. This is so fixed that the direction of rotation of the axle automatically puts ^{a receiver} into commission on the right side of the locomotive, with reference to the direction it is moving. There is a receiver on each side of the tender.

The current supply for the automatic train control equipment on the locomotive may be taken from the turbo-generator direct or from a storage battery independently charged or from a storage battery of smaller capacity floated across the turbo-generator and provided with the usual reverse current relay to prevent its discharge in case the turbo voltage should fall unduly. There are required about 25

1. The first step in the process of creating a new product is to identify a market need. This involves conducting market research to understand the preferences and behaviors of potential customers. Once a need is identified, the next step is to develop a concept that addresses this need. This concept should be innovative, feasible, and profitable. The concept is then refined through a series of iterations, taking feedback from potential customers and experts into account. Once the concept is finalized, the next step is to create a prototype. This involves building a physical model of the product to test its functionality and appearance. The prototype is used to gather feedback from potential customers and to make any necessary adjustments to the design. Once the prototype is approved, the next step is to develop a business plan. This plan outlines the financial aspects of the product, including the costs of production, distribution, and marketing, as well as the expected revenue and profit. The business plan is then used to secure funding from investors or lenders. Once funding is secured, the next step is to manufacture the product. This involves sourcing materials, hiring workers, and setting up a production line. The product is then distributed to retailers or directly to customers. Finally, the product is marketed through various channels, including advertising, public relations, and sales promotions. The goal is to create awareness of the product and encourage customers to purchase it. The entire process is a continuous cycle, with feedback from customers and experts being used to improve the product and the business plan over time.

watts continuously when the automatic control is in commission. A cut-out switch is placed in the relay box so that the battery current may be cut off when the locomotive is out of commission.

This system makes it possible for a train to move up to a stop signal without an automatic application of the brakes and without the use of acknowledging contactors, by the use of inductors placed along the road in combination with a time mechanism on the locomotive, the whole so organized that if a train passes from one inductor to the next with its speed sufficiently reduced, no brake application will take place. Upon reaching the second inductor, the time mechanism will again have closed its circuit so that it would not cause a brake application. This speed control arrangement is exceedingly flexible and rather simple, involving the same kind of parts as would be used in connection with an automatic stop, except that the time contactors are added. Speed restrictions are instantly removed when and if the signal ahead shows a more favorable indication.

CONTINUOUS INDUCTIVE CONTROL: * The secondary of a small 10 watt transformer is connected thru a reactance to the exit end of each track circuit in series with the primary battery which forms a part of the D.C. signal system. When a train occupies the track circuit a current from the secondary of this transformer at approximately 1.2 volts goes down one rail across the axles of the locomotive and cars and back

* See Diagram #3 for partial arrangement this circuit

along the other rail. This current induces a current in the receiving coils mounted on the cross members of the engine frame. This current is amplified and used to pick up the train control relay on the locomotive.. If a signal is indicating 'stop' the a.c. train control energy is cut off the track deenergizing the control relay , flashing a signal to the engineman and unless he releases the control within ten seconds makes a full service application of the brakes. A very fine example of the operation of "two speed" control is in existence between Sidney and Cheyenne on the U.P. and because it explains very clearly the operation of train control will be cited here under continuous inductive control. "On the 102-mile double track division between Sidney and Cheyenne, the Union Pacific operates six westbound and seven eastbound regular passenger trains, two westbound and one eastbound express and mail trains and about twelve freight trains each way each day. All of these trains are handled by locomotives equipped with automatic train control. In ordinary train operation there is sufficient spacing between trains so that a high speed indication is given normally; however, under certain conditions approaching stations or passing tracks it is necessary that trains approach or enter occupied blocks.

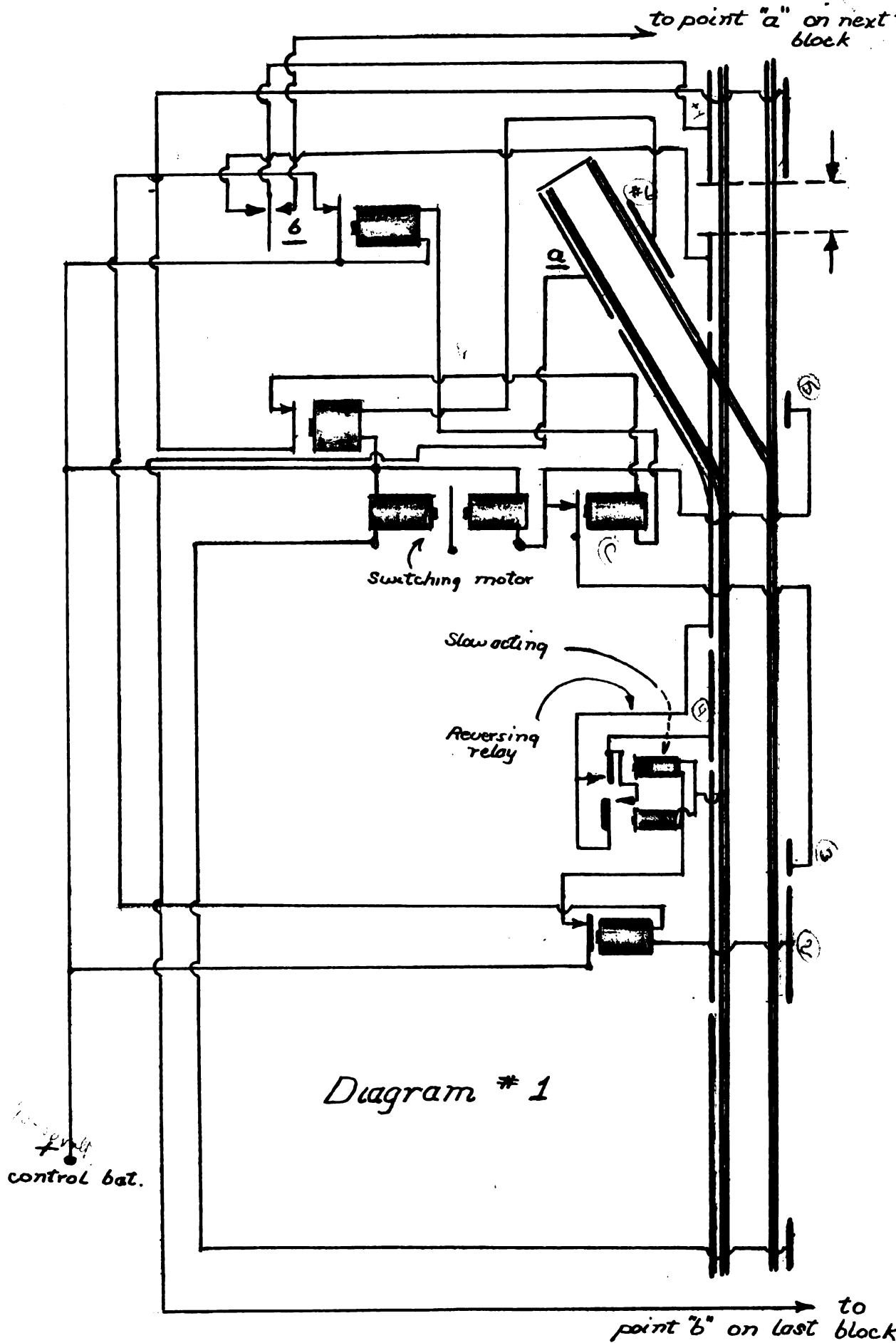
"In approaching a signal indicating stop an automatic brake application is made at braking distance from the signal unless the engineman acknowledges and reduces speed to less than 20 miles per hour. This speed limit is imposed not only in approaching the signal but also thruout the

the block governed by the signal. If the engineman should exceed this speed the brakes are applied automatically

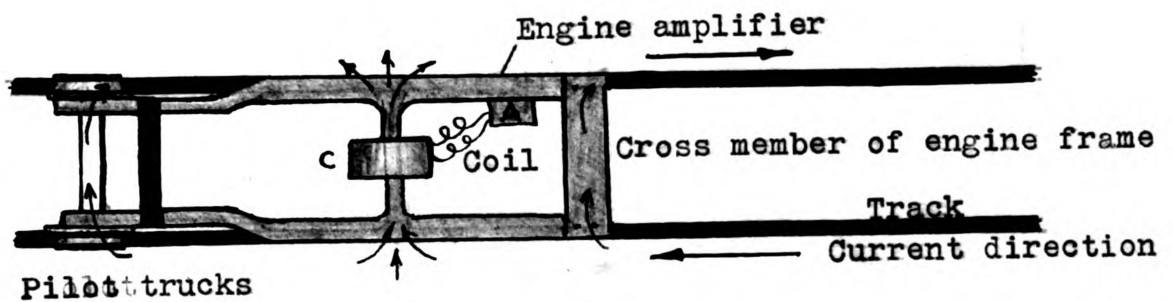
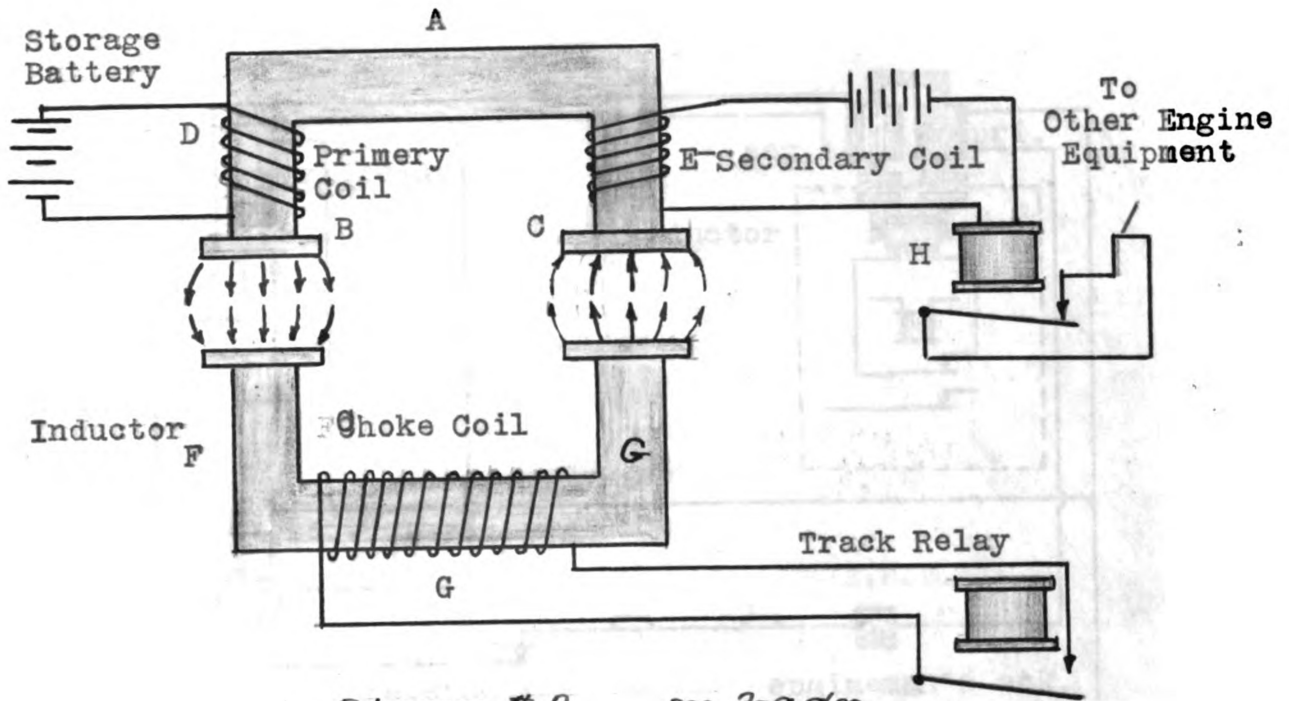
"The cab indicator has two lights, one or the other of which is burning at all times when operating in train control territory. The upper light is green, indicating "proceed" and is lighted normally. The lower lamp is red indicating "stop", or reduce speed to less than 20 miles an hour. The automatic train control cab signals supplement the automatic block signals in governing the use of blocks, and do not supercede the superiority of trains, or dispense with use of or the observance of automatic block or interlocking signals or other signals.

"When the cab indicator changes from green to red, the engineman acknowledges with the acknowledging valve, and if the speed is in excess of twenty miles an hour, must immediately reduce to less than that amount, and be prepared to stop. When a train is proceeding after having been stopped by an automatic home block signal or by automatic train control, if the cab indicator changed from red to green the train may resume normal speed. When within automatic train control territory and moving over track not so equipped, the engine must be kept below twenty miles an hour. Otherwise the speed control relay will function applying the service brakes to a full stop."

All types of train control do not shut off the throttle, steam being left on until engine reaches a dead stand.



Inductive Train Control



Continuous Control System

Diagram #3

Circuit
Auto-Manual Train
Control
Receiver

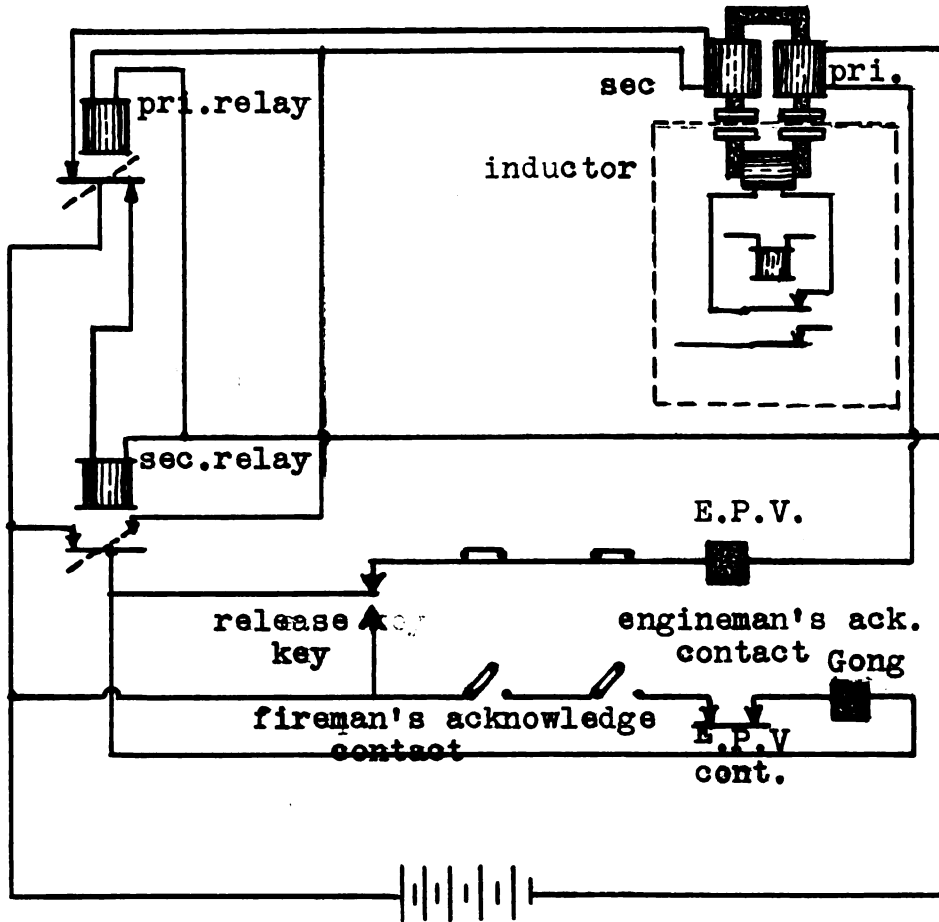
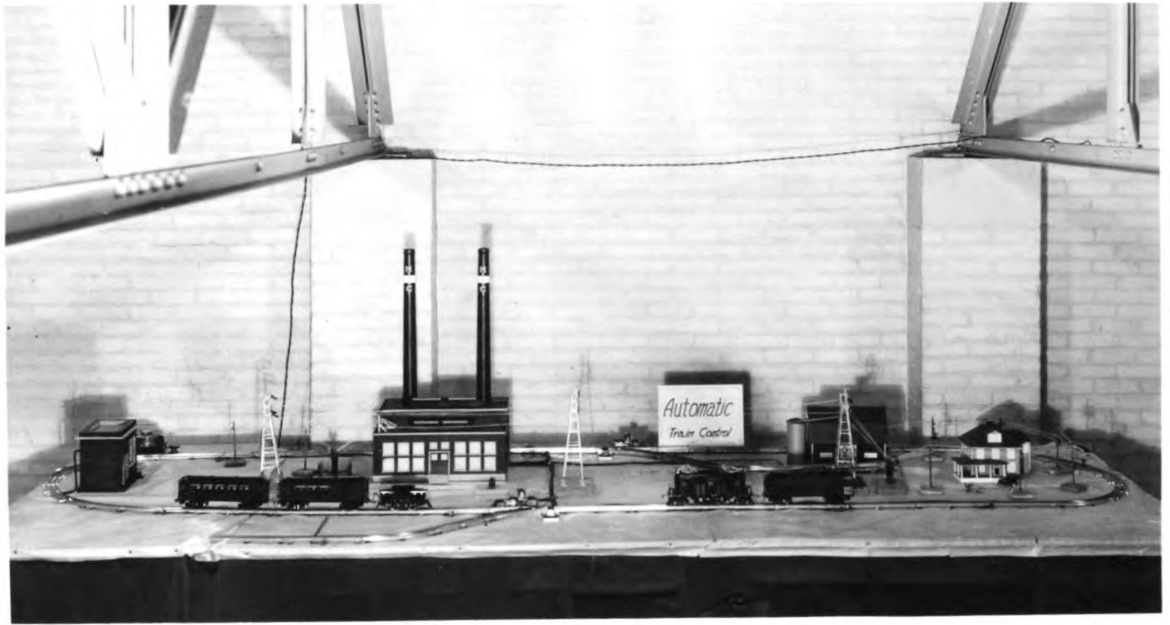
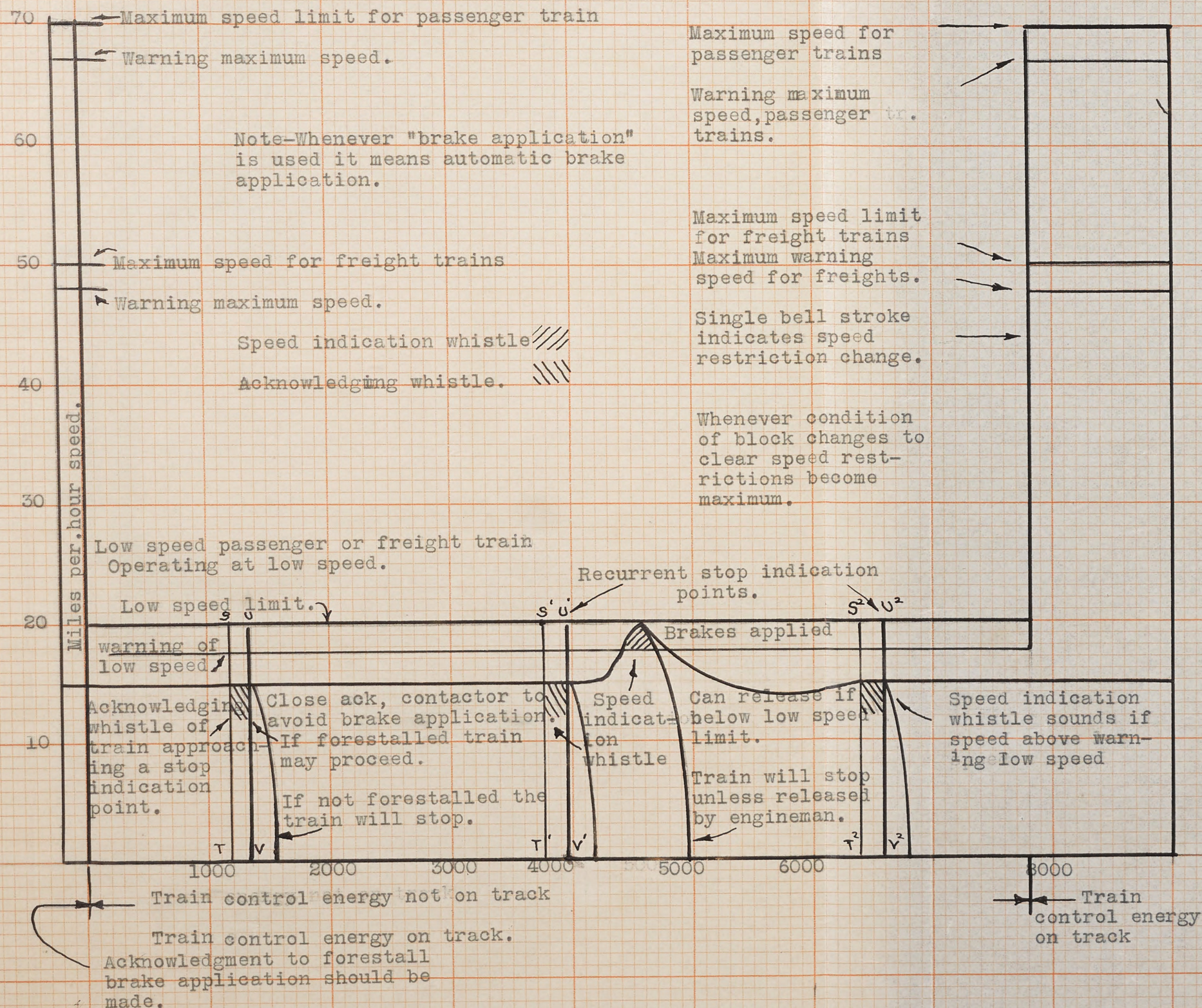
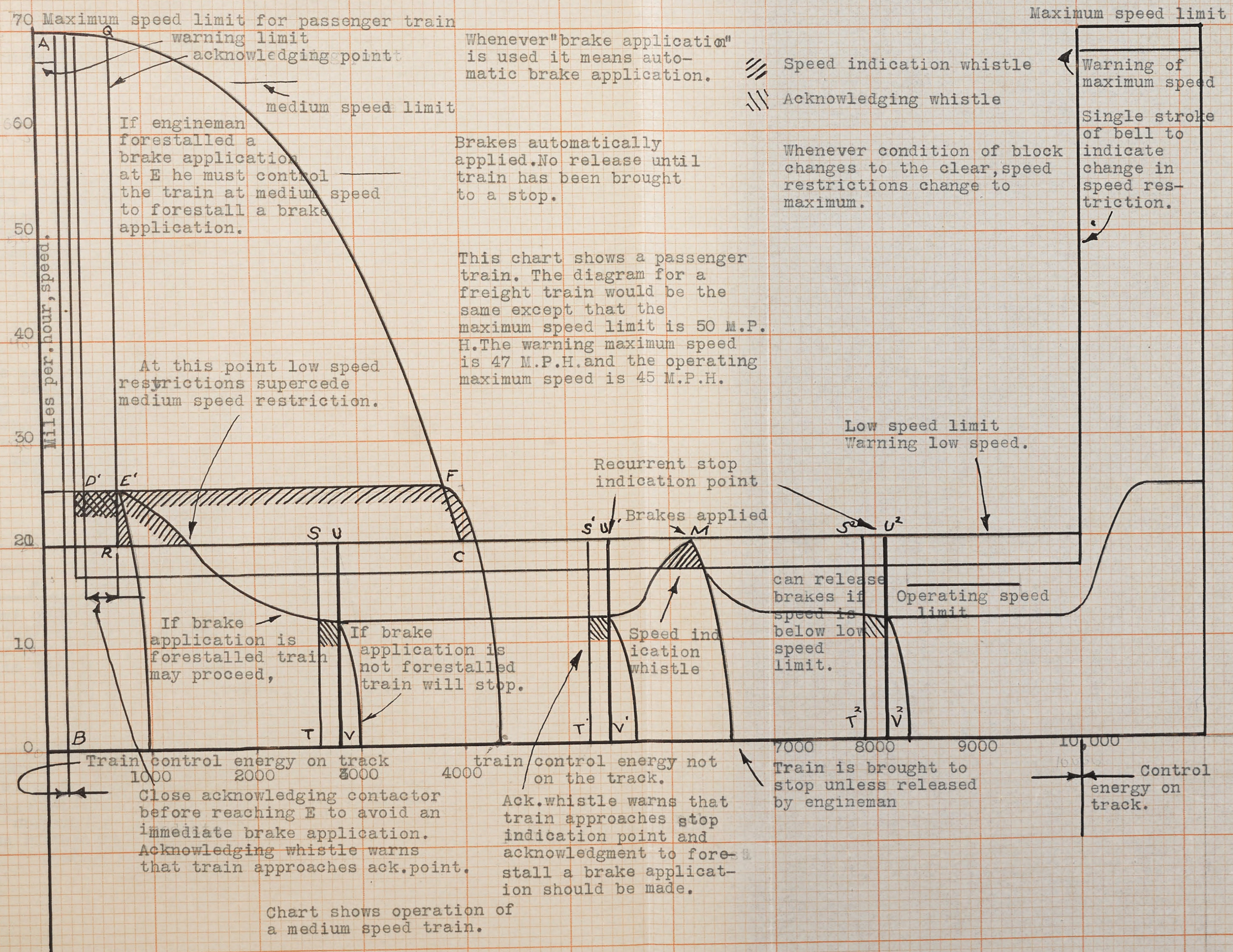


Diagram #2-a







Speed indication whistle sounds

Maximum speed limit

Warning maximum speed

Operating maximum speed

High speed passenger train

Train will be brought to a stop unless it is released by the engineman

Acknowledging whistle warns that train is approaching acknowledging point

acknowledging point

Speed indication whistle will sound at all times after train has passed point W and speed is above warning low speed.

This chart shows a passenger train. The diagram for a freight train would be the same except that the maximum speed limit would be 50 M.P.H.

The warning maximum speed is 45 M.P.H.

(speed in miles per hour)

Train energy on track

Brakes automatically applied no release until train has been brought to a stop

Medium speed limit

close approach before reaching E to avoid brake application

If engineman forestalls brake application at E he must control train below medium speed limit to forestall brake application

Warning medium and low speed limit.

Operating at low speed (15 M.P.H.). If brake application is forestalled train may proceed.

Operating limit and low speed

If engineman did not forestall a brake application at E, train will be brought to a stop.

Stop indication point every half mile.

Acknowledging whistle warns that train has neared stop indication point C.H. and should ack. to forestall brake application.

When ever "brake application" issued means automatic brake application

Acknowledging whistle

Speed indication whistle

(Maximum speed limit

warning of maximum speed.

Single bell indicates change in speed restriction.

Recurrent stop indication points

Brakes applied.

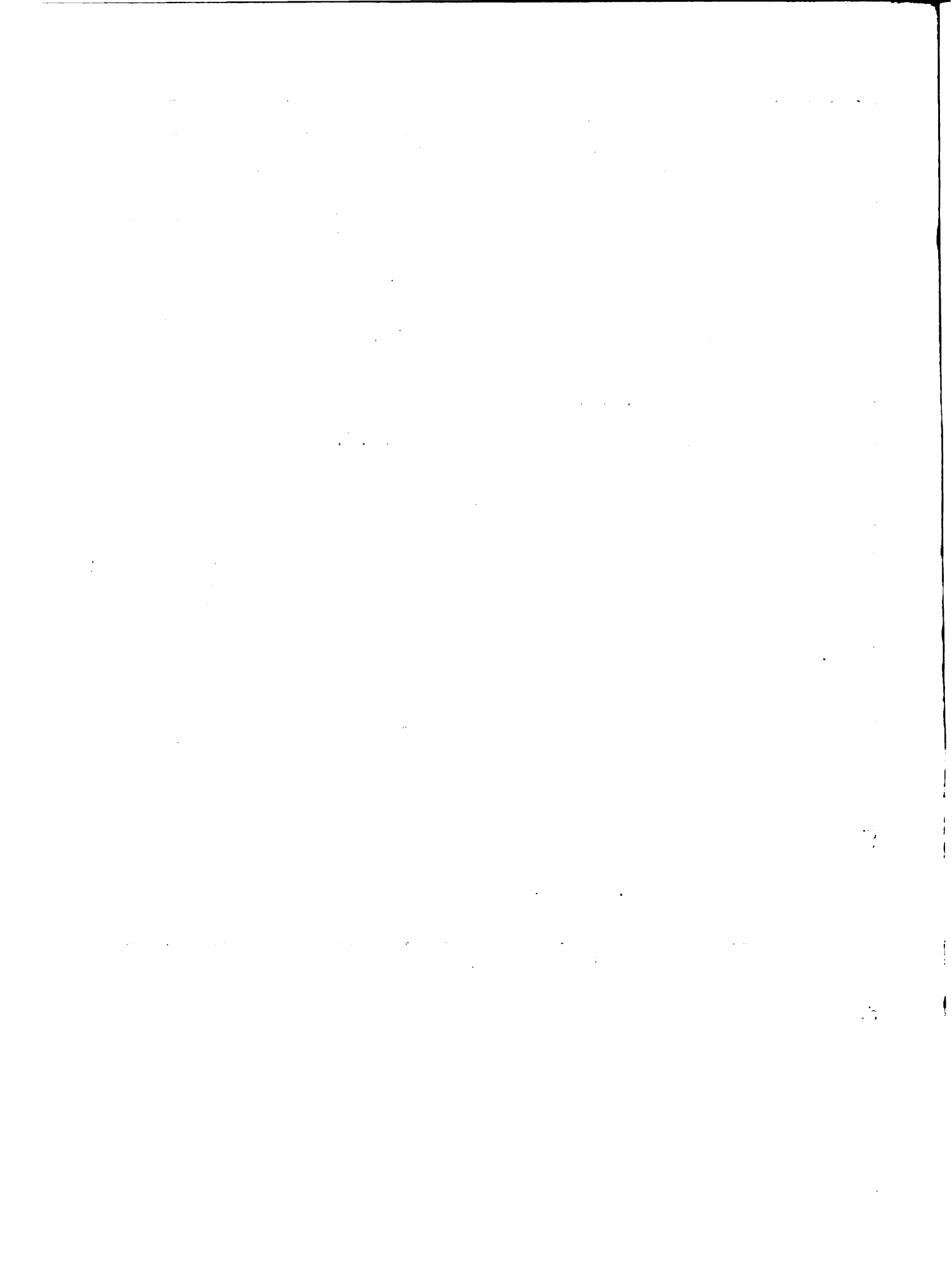
Can release if speed below limit (low)

speed indication whistle

Train will be brought to a stop unless released by engineman

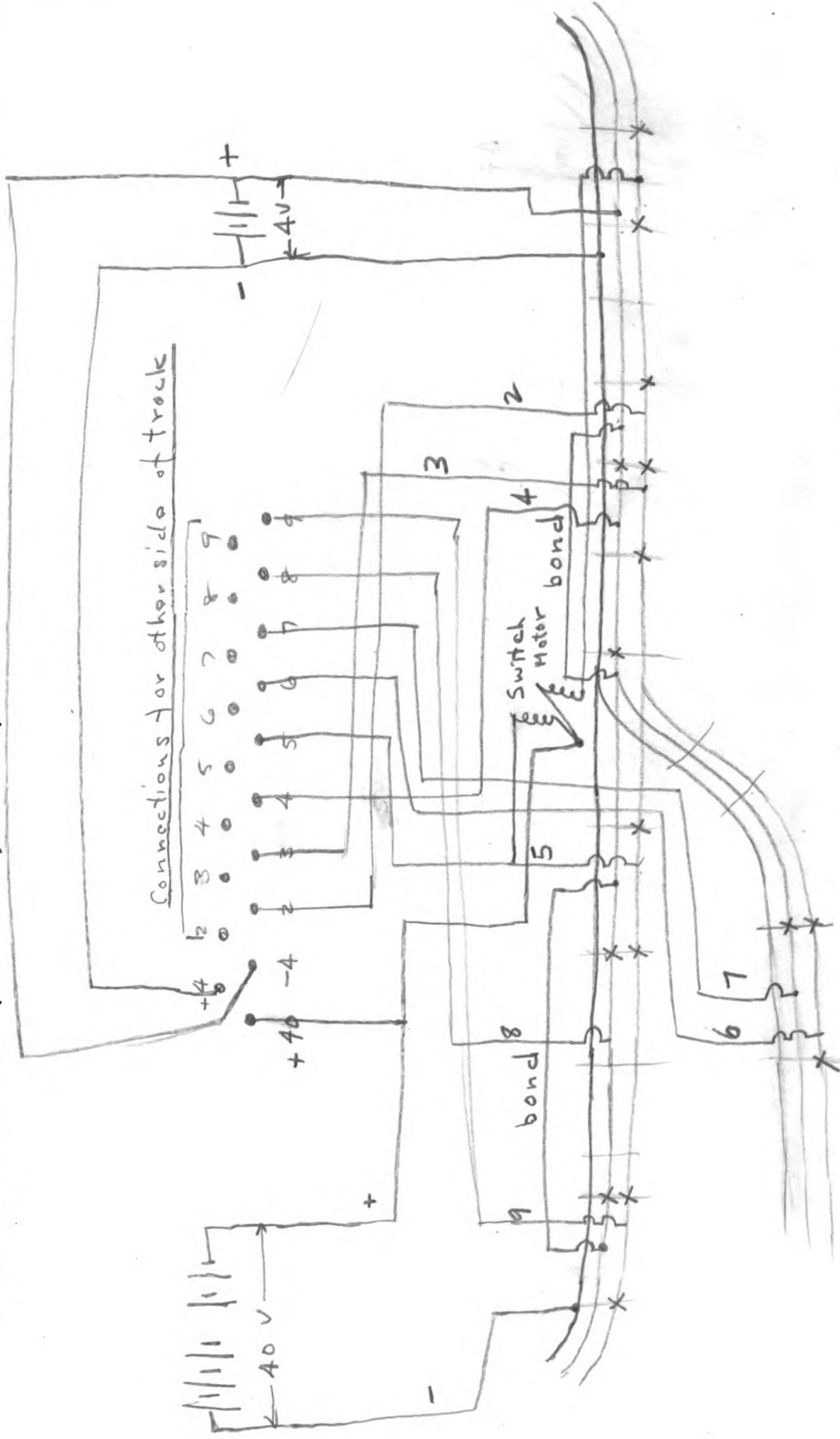
As block changes to clear speed restrictions change to maximum.

train control energy not on track
6000 7000 8000 9000 10,000
Train control energy on track



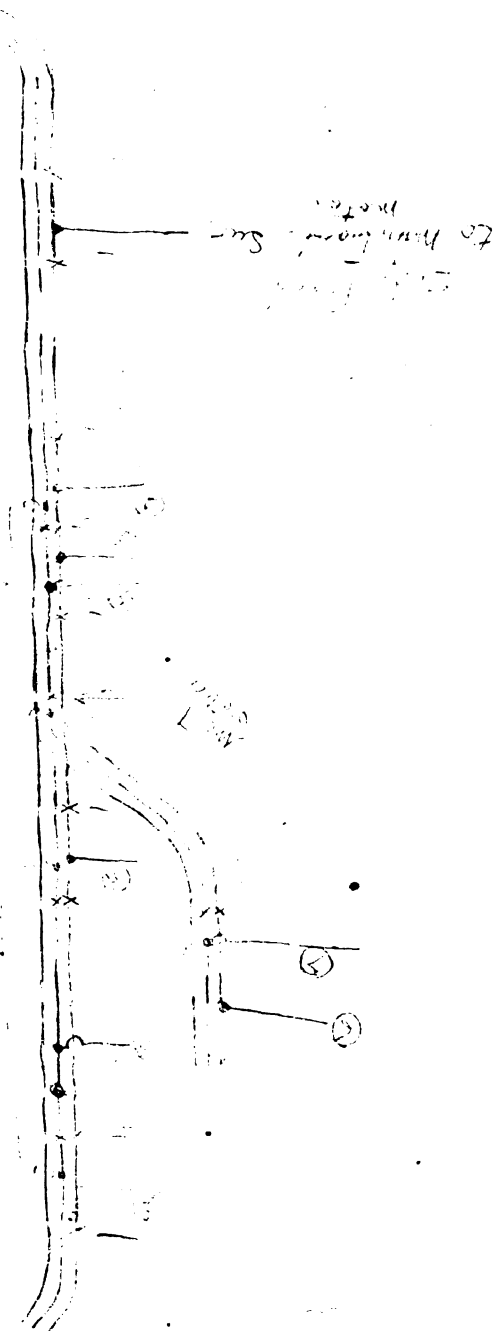
Connection Diagram for Automatic Train Control

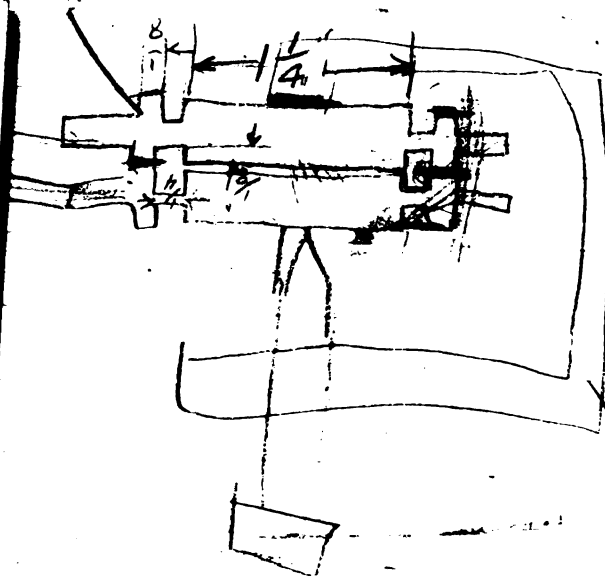
Is advisable so as to provide good regulation to bond both the inside and middle rails at various points, excepting at sections feed by relays.



Note! - Other Side of Track is exactly Similar

Quarry





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