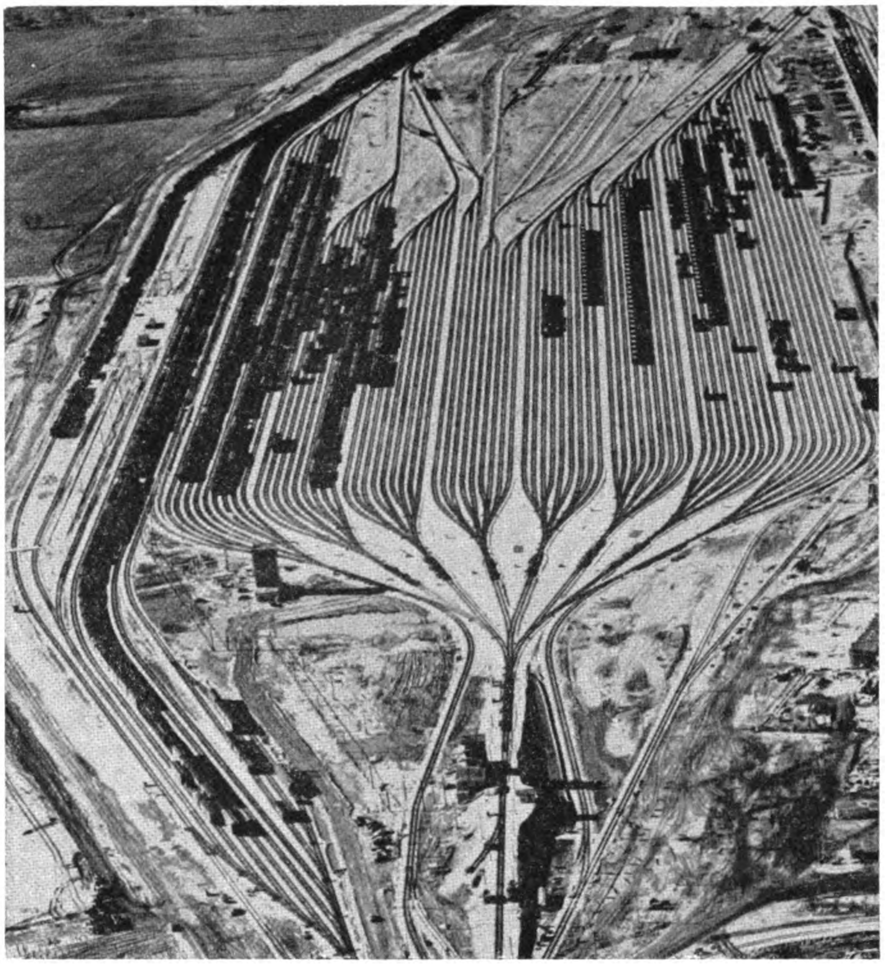
Hugh C. Kendall, a native of Rochester, Minn., obtained his bachelor's degree from Carleton College. He did graduate work at Northwestern University, earning a master's degree in physics in 1940. In 1941, he became a research associate at Massachusetts Institute of Technology Radiation Laboratory. Subsequently he served as Deputy Director of the Advanced Service Base of the Radiation Laboratory in Paris during World War II.

Mr. Kendall joined General Railway Signal Company in 1945. He was appointed Director of Research in 1956. He has specialized in electronics, being particularly concerned with the problems of automatic car retardation in gravity-type classification yards.



How Retarder Controls Function

. . . at Young Yard on the NYC

Class-Matic system developed by General Railway Signal Co. was installed at New York Central's latest retarder classification yard at Elkhart, Ind. How this system functions is explained in this article by GRS Director of Research Hugh C. Kendall. He gave a resumé of this article, as well as illustrated slides, at the Signal Section, AAR convention in September, 1958.

There are many factors which influence the rolling behavior of freight cars in gravity classification yards. Some of these factors are well understood. Others are more subtle since they are related to speed, weight, standing time, weather, track conditions, and other variables. Also, one must not forget the perversity of inanimate rolling objects.

The idiosyncrasies of car behavior in classification yards take on very real significance in the layout of yards and in the design of automatic retardation systems. It is convenient to think of these systems as consisting of two principal elements, namely, control elements and prediction elements.

The control elements in a system include the retarders and associated apparatus which is required to bring about agreement between the actual and desired leaving speed of a car from a retarder. In general, these elements can achieve a high degree of accuracy in their function if they are supplied with the desired leaving speed and the dynamic performance of the car while it is under retardation. Control elements have been developed today which are fully commensurate with the task.

Several Prediction Elements

The prediction elements in a system usually include one or more car performance test sections ahead of the last point of retardation, distance to go equipment, and an analog or digital computer with associated panel of control knobs used to introduce preset information. As a car moves toward the last point of retardation, the measured performance of the car in one or more test sections, together with distance to go and preset information are fed to the computer, which solves an equation of motion for the car to obtain the desired release speed of the car from the last point of retardation. In order to couple the car at a pre-selected speed at a given distance on a body track, it it absolutely essential that all factors relating the rolling behavior of the car in the test sections to the rolling behavior of the car around the curve and on the body track, be known in advance of the last point of retardation. This is a formidable requirement which is met in varying degrees by all systems of automatic retardation. The percentage of stalls and the spread in coupling speeds above and below the desired speed in a yard can be largely attributed to shortcomings in the prediction elements of the system.

Let it suffice to say, that from the standpoint of overall yard operation, it is very important to do the best possible job in both elements of the system. It is probably easier however, to do a better job on control than on prediction.

Prediction elements in a system often must function on incomplete information on changes in the rolling behavior of a car which occur as a function of time. The expected rolling behavior of a car beyond the group retarder is frequently a long range forecast based upon test section measurements made on the car over a relatively small portion of its total travel time in the yard. One hopes that if a car is going to change its rolling behavior later on, that it will impart this information to the test sections. History has proven that cars can be very cantankerous in this respect. About the best one can do is to continuously relate the rolling behavior of cars on the body tracks to their prior test section behavior on the premise, that the mean relationship thus established will reasonably apply to following cars. Changes in this relationship would be detected, and compensating adjustments made to the computers either automatically or manually. Little help however can be offered to a specific car, which for example, upon leaving the test sections proceeds to leak sand on the rail ahead of its wheels. This car would probably receive retardation in the group retarder, when what it really needs is a push. The next of kin to this car is one which arrives in a test section with its trucks skewed, and upon being shaken up in the group retarder, has its trucks unskewed. If the trucks remain unskewed on the body track, one will wish more retardation had been applied.

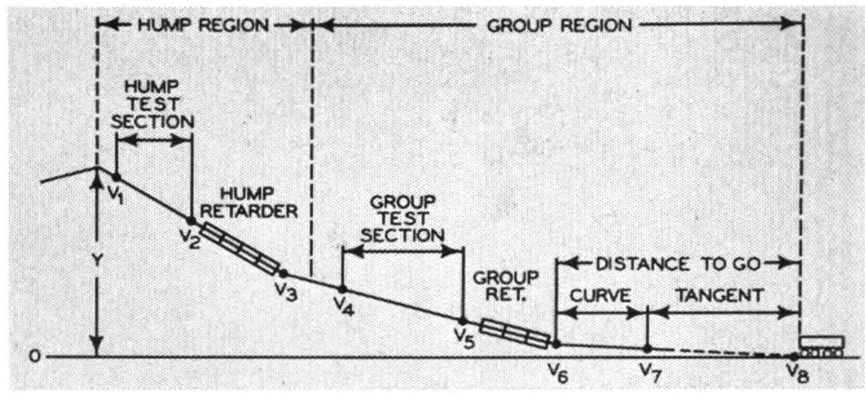


Figure 1 shows elevation typical of hump and group regions (not to scale)

Young Yard Characteristics

The GRS Class-Matic equipment was installed at Robert R. Young Yard at Elkhart, Ind. in December, 1957. The entire yard was placed in service on January 10, 1958. The yard is located on a natural sand table just south of the main line, to the west of Elkhart (RS&C, March 1958, pages 28-38).

There are 72 classification tracks, 8 group retarders, and a hump retarder. The height of the hump is 22 ft and the longest classification tracks in the outside groups have a capacity of 68 cars. The bulk of traffic in this yard flows to groups 1, 2, 7, and 8, with moderate traffic flowing to groups 5 and 6. There is little traffic to the center groups.

Figure 1 shows an elevation typical of the yard, not necessarily to scale. The height of the hump above the coupling point is shown as "Y" in the figure, and the velocity of a cut at various points on the profile is labelled V1 through V8. The hump region consists of a tangent test section, cut weight detector, long cut detector, and hump retarder. The release speed for each cut from the hump retarder is made proportional to the measured value of the ratio of friction to weight of the cut in the hump test section. This ratio will be henceforth referred to as F/W and is expressed

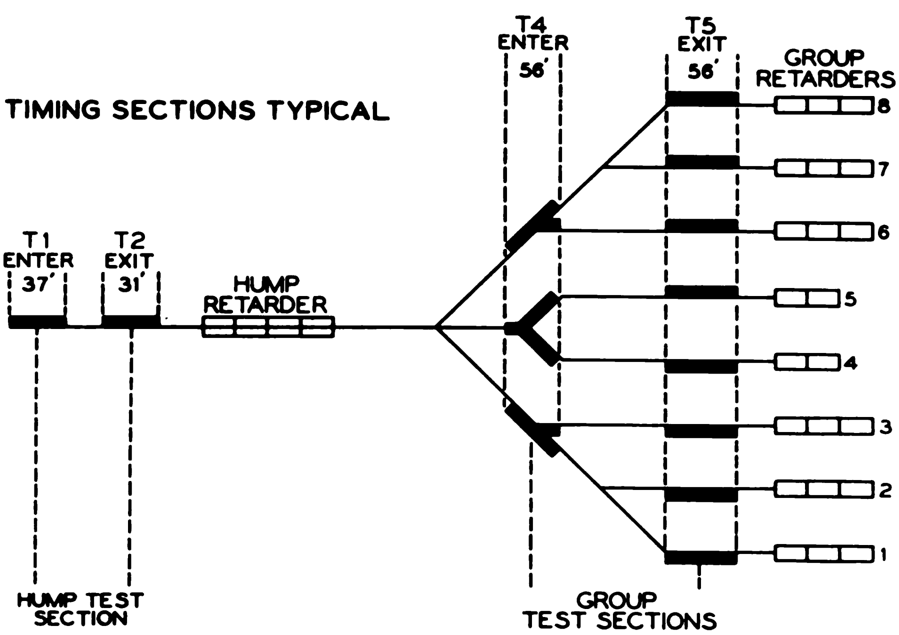
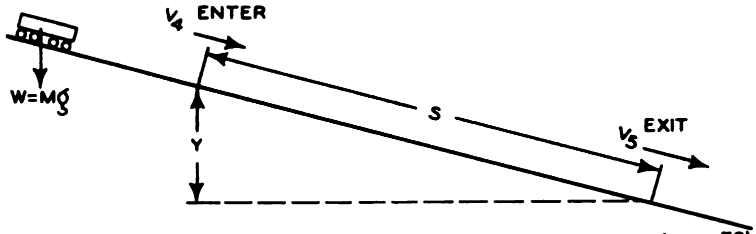


Figure 2 shows a plan view of typical timing sections of hump and group test sections

in terms of per cent equivalent grade. (The ratio F/W is sometimes referred to as R_T. F/W expressed in per cent equivalent grade equals R_T expressed in 20 lbs per ton.) There is no further use made of the hump test section information after the cut leaves the hump region.



$$\frac{MV_5^2}{2} = \frac{MV_4^2}{2} + WY - W\left(A\Delta + \frac{FS}{W}\right)$$

KINETIC ENERGY OF CAR LEAVING TEST SECTION = KINETIC ENERGY OF CAR ENTERING TEST SECTION + POTENTIAL ENERGY DUE TO HEAD − ENERGY LOSS DUE TO CURVE AND TANGENT ROLLING RESISTANCE

$\frac{FS}{W}$=EQUIVALENT HEAD LOSS DUE TO TANGENT TRACK ROLLING RESISTANCE

$A\Delta$=EQUIVALENT HEAD LOSS DUE TO CURVE TRACK ROLLING RESISTANCE

Figure 3 shows an elevation view of a typical group test section

Only Single or Double Car Cuts

Because of physical space limitations, the longest cut whose rolling characteristics can be measured in either the hump or group test sections, is 130 ft. Cuts which are longer than this are automatically detected ahead of the hump retarder and cause the hump and group test section information to be discarded. In place of the measured rolling characteristics of a long cut, a most probable value of rolling resistance is automatically switched into the computers. In view of this fact there are only single or double car cuts humped at Young Yard.

The weight of a cut in one of three categories (light, medium, or heavy), is used in making computations by all of the computers in both regions. It is also used in the control of all retarders. Weight and long cut information therefore is transferred from the hump region where it originates, to the group region, via an information passing system which operates from the automatic switching system and track circuits.

The group region starts at the base of the hump retarder and continues to the coupling point. There are eight group regions at Young Yard, each containing identical equipment. For simplicity, only one of these regions is shown on the profile. Each region consists of a group test section, group retarder, and distance to go equipment. The group test section contains both curve and tangent track and is used to again measure the rolling resistance of each cut before it enters the group retarder. The release speed of cuts from the group retarder is calculated by the group computer as the front wheels of the cut leave the group test section at a point approximately 20 ft ahead of the group retarder. Beyond the group retarder the track is divided into two zones, namely, curve and tangent. Distance to go equipment stores information as to the position of the coupling point with respect to the end of the retarder for each body track.

Figure 2 shows a plan view of the timing sections which make up the hump and group test sections. Each timing section consists of two flange operated treadles which are spaced on the rail to a tolerance of plus or minus ¼ in. The treadles are spaced 37 ft and 31 ft respectively for the two hump timing sections. The treadles in the group timing sections are spaced 56 ft apart. Associated with each timing section in the yard is an electronic counter which is started and stopped as the front wheel of a cut actuates the start and stop treadle in the timing section.

The time interval between the operation of the start and stop treadles in each timing section is measured to an accuracy of .023 per cent and is expressed as a 5-digit number which can have 20,000 possible values. The 5-digit numbers expressing the entrance and exit time intervals in the test section are used by the associated rolling resistance computer in determining the F/W for each cut. It will be seen that there are eight group test sections. These test sections are made up of eight exit timing sections and three entrance timing sections. Certain entrance timing sections are shared by the group test sections.

Figure 3 shows a typical group test section. The elevation through the test section is shown as "Y," and the length of the test section is shown as "S." The purpose of the test section is to determine the total energy loss sustained by a cut due to curve and tangent track rolling resistance. This determination is made in accordance with the energy equation shown. The kinetic energy of a cut leaving the test section is equal to the kinetic energy of a cut entering the test section, plus the potential energy due to the drop in elevation through the test section, minus the energy loss due to curve and tangent track rolling resistance.

Energy Loss Due to Friction

It is convenient to think of the ratio FS/W as the equivalent head loss due to tangent track rolling resistance, and the product $A\,\Delta$ as the equivalent head loss due to curve track rolling resistance. The sum of these factors, multiplied by the weight of the cut, represents the total energy loss due to friction.

Figure 4 shows the relationship between F/W and the group test section factors. "Y" and "S" are constants for all cuts. The factor $A\,\Delta$

$$\frac{F}{W}=\frac{1}{S}\left[Y - A\Delta - \left(\frac{V_L^2 - V_E^2}{2g_0}\right)\right]$$

Figure 4 shows the relationship between F/W and the group test section factors

$$V_6 = \sqrt{V_8^2 + 2g_0 \left[\left(\frac{F}{W}\right)_{68} S_{68} - (Y_6 - Y_7) - (Y_7 - Y_8) + A\Delta_{67} \right]}$$

Figure 5 is the group retarder release speed equation which is solved for each cut

representing the equivalent head loss due to curve track rolling resistance within the test section, is not measured explicitly for each cut. The specific value of A Δ used in the computation of F/W for each cut is a function of the weight of the cut. The factor g_0 is the acceleration due to gravity, modified by the weight of the cut to account for the rotational energy in the wheels. V_E is the measured entering velocity of the cut in the test section and V_L is its measured leaving velocity.

The accuracy to which the F/W of a cut can be dependably determined in the test sections is a summation of all of the errors which can be expected to occur in the factors involved. An examination of the probable error in these factors indicates that the F/W of a cut can be measured in the group test sections to an accuracy of plus or minus .17 per cent equivalent grade, or plus or minus .34 lbs per ton.

The ratio F/W determined in the group test sections is modified by two additional factors relating test section measurements ahead of the group retarders to actual cut behavior on the body tracks. These factors are obtained by a direct comparison of the actual behavior of the cuts on the body tracks to the behavior of these same cuts in the group test sections.

Figure 5 shows the group retarder release speed equation. This equation is solved explicitly for each cut entering the group retarder. V8 is the desired coupling velocity. F/W_{68} is the predicted tangent rolling friction of the cut, based upon the measured value for F/W in the group test section. S_{68} is the distance between the end of the retarder and the coupling point. The loss in elevation between the end of the group retarder and the end of curve is shown as Y_6-Y_7. The loss in elevation between the end of curve and the coupling point is shown as Y_7-Y_8. The A Δ_{67} is the predicted head loss to be sustained by the cut on the curve after the group retarder. The specific value of A Δ_{67} used in the computation of the desired leaving speed for a given cut is a function of the weight of the cut, and the average head loss sustained by prior cuts on the particular curve.

Group Control Region

Figure 6 is a simplified block diagram of the organization of a group control region. The test section ahead of the group retarder is shown with its associated rolling resistance computer. As the cut leaves the test section, the F/W for the cut is computed and passed to the release speed computer, together with distance to go information, weight, body track grade, and the curve factor. The computed desired release speed is passed as a voltage to the retarder control unit, together with the actual velocity of the cut measured by the radar unit. The single 10,525 mc radar unit, located between the rails, approximately 20 ft ahead of the retarder, is used as the source of speed information while the cut is in the retarder. This is the only use of radar information in the system.

As the cut enters the retarder, the amount of pressure which is applied is a function of the weight of the cut, the instantaneous difference between the actual speed of the cut and its desired leaving speed, and the deceleration of the cut under retardation. The deceleration information is derived from the radar signal and plays a major role as a feedback element in the closed loop control system.

Figure 7 shows the relationship between the actual velocity of a typical single good rolling cut and its progress through the group retarder. The cut is shown entering the retarder at velocity V5 and the computed release velocity is shown as the dotted line, V6. As the first truck of the cut enters the retarder, it receives retarding force, which is augmented as the second truck of the cut enters the retarder. The deceleration of the cut under retardation is rapid until the velocity of the cut approaches the desired release velocity. At this time the retarder pressure is gradually reduced as a result of the feedback of deceleration information into the control system. As the velocity of the cut reaches the desired leaving velocity, the retarder is fully released, causing the cut to accelerate slightly under gravity. From this point on, minor retarder pressure is caused to cycle on and off, holding the velocity of the cut to small oscillations whose maxima lie slightly above and below the desired release velocity as the cut exits from the retarder.

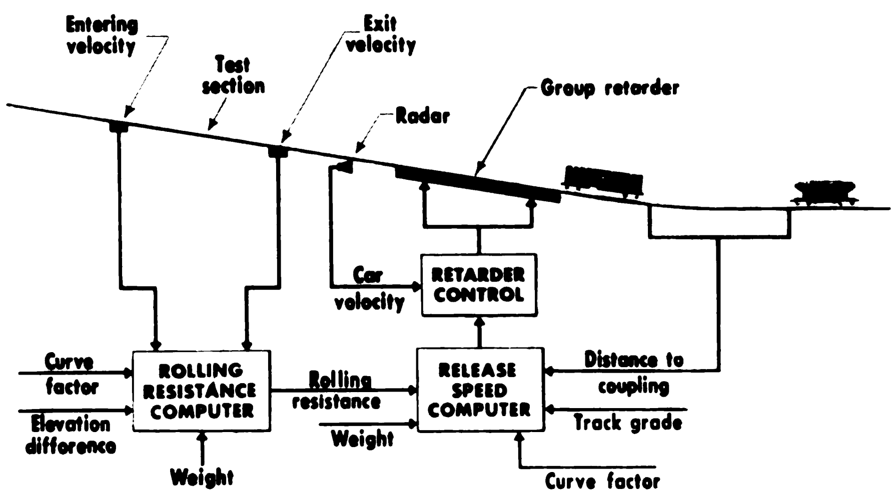


Figure 6 is a simplified diagram of the organization of a group control region

Computer Equipment

The retarder control tower at Young Yard is six stories high, with the operator on the 6th floor, the computers on the 5th floor, the automatic switching and distance to go equipment on the 4th floor, the power switchboard and batteries on the 3rd floor, a communications shop on the 2nd floor, and

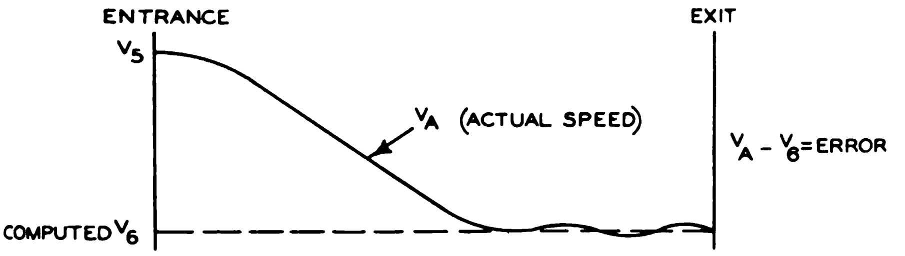


Figure 7 shows the speed of a single-good-rolling cut through the group retarder

the signal department maintenance shop on the ground floor. The computer room on the 5th floor of the tower is 22 ft square and is air conditioned.

Figure 8 shows the hump retarder control cabinet. The left hand bay contains the retarder control relays, plus the relays associated with the storage and transfer of weight and long cut information from the hump to the group regions, together with relays associated with the hump test section. At the bottom of the center bay, there are 2 retarder control units. The top control unit operates the first half of the retarder in connection with a radar unit located approximately 20 ft ahead of the hump retarder. The lower unit operates the second half of the hump retarder in connection with a radar unit located at the midpoint of the hump retarder.

Above the retarder control units are the two electronic counters associated with the hump test section. At the top of the center bay is the master control panel for the hump region. The three meters at the top of this panel display respectively the measured F/W for each cut entering the hump retarder, the computed release velocity, and the error in retarder control. Below these meters is a miniature diagram of the track and field equipment associated with the hump region. The operation of the field equipment and the progress of the cut through the hump region is displayed on lights associated with this track diagram. Below the track diagram are located indication lights associated with the origination and transfer of weight and long cut information within the hump region.

This panel contains pushbuttons and switches, making possible the complete checkout of this cabinet in the absence of traffic, by following a set routine and observing the indication lights on the panel. The normal flow of traffic through the hump region also causes the indication lights to display a preset pattern which enables a maintainer to quickly isolate difficulties should they occur in this cabinet, or in any of its associated field apparatus.

The right hand bay contains the analog computer for the hump region. At the top of this bay is a computer test panel whereby the function of the entire computer can be checked out, using the meters and selector switches. The panel of knobs below the test panel enables preset information to be entered into the computer. The remainder of this bay is the precision analog computer and its associated stabilized power supplies.

Group Retarder Controls

Figure 9 shows a group retarder control cabinet. One of these cabinets is used in each of the eight group control regions. The physical makeup of the cabinet is very similar to the hump control cabinet. Associated with this cabinet is the distance to go storage equipment for one group located on the floor below, a single radar unit ahead of its group retarder, and the exit timing section for its group test section. The entrance timing information for its group test section is passed to the group cabinet. The left hand bay of the cabinet contains retarder control and test section relays, similar to the hump.

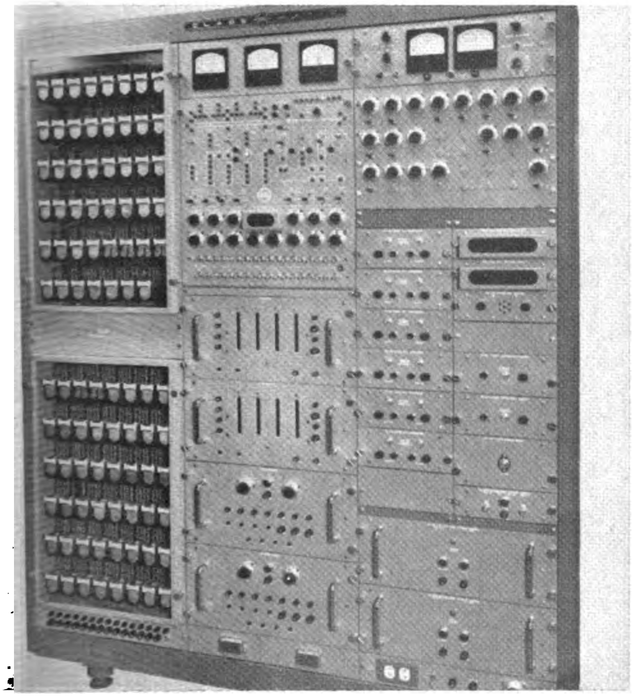


Figure 8 shows the hump or master retarder control cabinet

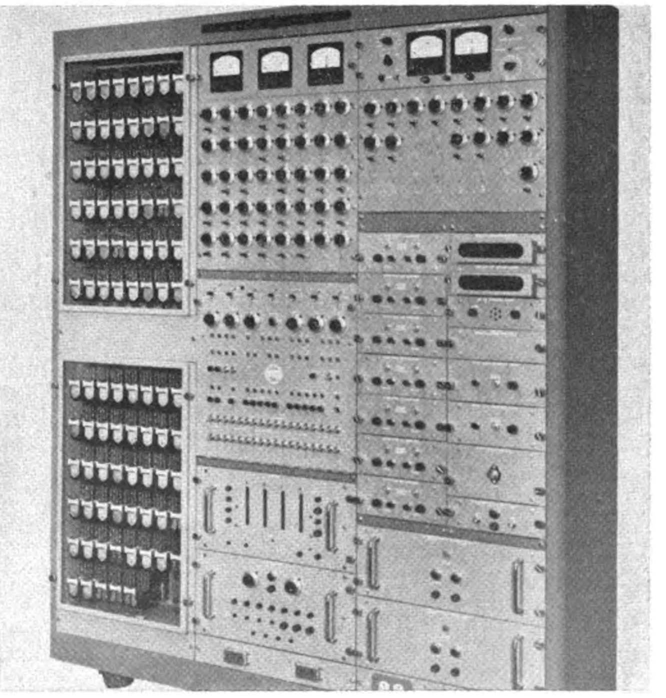


Figure 9 shows one of the eight group retarder control cabinets

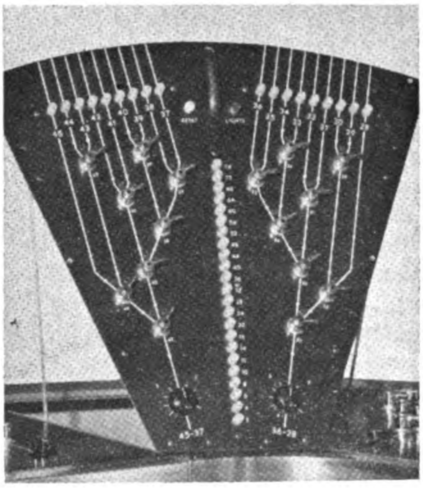
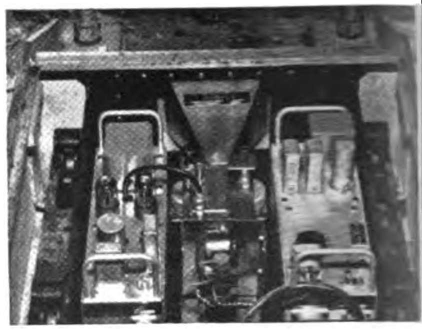


Figure 10 shows the track-fullness panel

Figure 11 shows the radar unit



Transmitter-receiver of 10,525 mc radar

The center bay contains a single retarder control unit at the bottom, an electronic counter for the test section exit timing information, a master control panel, a portion of the computer control knobs and meters displaying F/W, leaving speed, and retarder control error. The right hand bay contains the analog computer, power supplies, computer test panel, and the remainder of the computer control knobs. There are 54 control knobs on the two computer control panels. Many of these control knobs are associated with introducing individual track characteristics into the computer for the nine tracks in the group. The analog computer is somewhat more involved than in the hump cabinet since the computations are more complex at this point. Identical test and function indication facilities, which were described for the hump control cabinet, are incorporated in each group cabinet.

Both the hump and group cabinets are equipped with automatic check circuits and associated apparatus. With no traffic in the region, a given control cabinet is at rest and an automatic check problem is applied to the computer in lieu of test section information. The computer output as a voltage must agree within specified tolerances with a reference voltage which is preset to the correct answer to the check problem. A failure in any portion of the computer, which causes the answer to the check problem to drift past the tolerance limits, removes stick energy from a computer check relay.

The retarder control unit is checked during the period of rest by substituting a calibrated audio signal in lieu of the doppler signal from the radar units. The audio signal causes the speed channels in the retarder control unit to respond and actuate the retarder control relays which at that time are not connected to the retarders. In the event of failure, stick energy is removed from a retarder control check relay.

The position of all test switches on the master control panel which affect the normal operation of the cabinet, is checked. In the event that one of these switches is inadvertently left in the wrong position at the time a cut enters the region, stick energy is removed from a maintainer check relay.

Cut Goes Through Test Section

As a cut enters the region and proceeds through the test section, a definite preset sequence of events takes place with regard to the function of the field equipment and the associated apparatus in the control cabinet. In the event that this sequence is interrupted, or does not follow a preset pattern, stick energy is removed from a sequence check relay.

As the front end of the cut is about to enter the retarder, the check relays must be energized or an alarm bell is sounded on the retarder control machine, warning the operator that manual control should be exercised on the cut in the retarder.

The role of automatic check facilities has been found to be an important one from the standpoint of establishing and maintaining retarder operator confidence in the system. The operators have learned to rely on the system explicitly unless they are warned by the system to take manual action themselves.

The intermediate control cabinet serves to pass weight and long cut information from the hump region to the group regions, and in addition, originates and passes the group entrance timing section information to the appropriate group computer. A test panel at the top of the rack permits the complete checkout of the information transfer system, and is used in the normal preventative maintenance program.

Figure 10 shows the track fullness panel on the retarder control machine for the distance to go equipment. Associated with each track in a group is a luminous track button, shown at the top of the panel. Each pushbutton serves as a clearance track indicator, as well as a distance to go interrogator for that track. An operator wishing to reset the distance to go storage for a given track makes two simple operations. He first pushes the desired track button on the group diagram, which lights up the distance to go indicator, much like a thermometer, showing the distance to go for that track. The distance to go for that track is reset by pushing the appropriate distance button on the indicator. Cars normally are counted into each track. He need only correct the distance to go for a given track as the track is pulled, or in the event a cut stops short of coupling. Automatic means for doing this have been developed, and are presently undergoing trial.

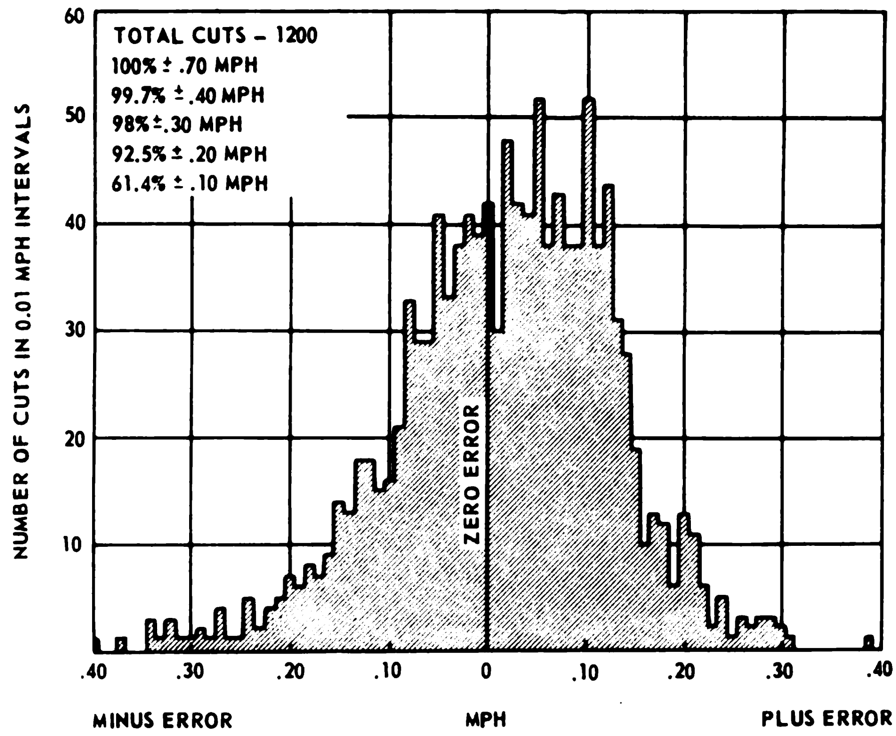
Figure 11 shows the radar unit mounted ahead of each retarder in the yard. The 10,525 mc doppler radar transmitter-receiver and associated electronic equipment are housed in a weatherproof shock-mounted box within a boiler plate ramp. In the eight months of operation at Young Yard, only one of these units has been replaced. This was torn out by a dragging brake beam on a backward move over the unit.

Figure 12 shows a plot of recently taken data on group retarder control error for 1200 typical single and double car cuts under service conditions having release velocities from 5 to 20 mph. The control error in .1 mph intervals is shown as the horizontal axis and the number of cuts falling within each .01 mph control error interval is shown as the vertical axis.

Figure 13 shows the most recent coupling data taken under service conditions at Young Yard. This data was taken during the month of August by the New York Central signal department. The predominance of the traffic occurred in groups 1, 2, 6, 7, and 8. A total of 190 cuts were observed: 2.1 per cent of the cuts coupled between 6 and 7 mph; 83.5 per cent of the cuts coupled between 1 and 6 mph; and 13.4 per cent of the cuts stalled on the tangent track short of coupling.

Controls on the machine which were originally intended for the operator's use in making vernier adjustments on the release speed of cuts from the group retarders, were disconnected from the system shortly after the yard went in service. A single control is used to modify the predicted performance of cuts on the curves after the group retarders on a yard basis during conditions of severe winter or summer weather.

In order to maintain a low spread in coupling speeds above and below the desired coupling speed in a yard, the factors relating the rolling behavior of cars in test sections to the rolling behavior of the same cars on the body tracks must not be allowed to change appreciably without making compensating adjustments to the prediction elements in a given system. It is a well established fact, that certain of these relating factors do change as a result of the deterioration in the condition of the curves and body tracks through usage, and lack of track maintenance. For some time, there has been a need for effective and transportable instrumentation which would enable a rapid and accurate evaluation of the factors relating the two behaviors, such that the prediction elements in any system of automatic retardation can be maintained in up to date adjustment with respect to changing track conditions in a given yard.



CONTROL ERROR DISTRIBUTION

Figure 12 shows plot of group retarder control data for 1200 single and double-cut cars

ROBERT R. YOUNG YARD

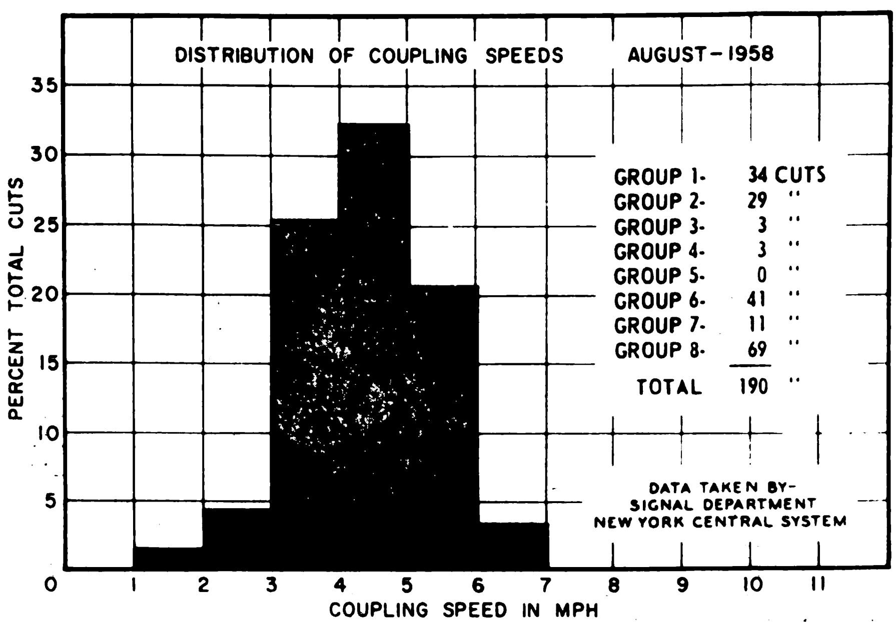


Figure 13 shows coupling data under service conditions at NYC's Young yard

The new GRS Mobile Laboratory truck has been designed to fulfill this need. It is now available with its crew of engineers for track evaluation purposes in any yard, automatic or manual. The truck is now at Robert R. Young Yard completing an evaluation of yard track changes which have occurred since January of this year. The settings on the computers at the yard will be examined and readjusted where necessary to compensate for these changes. (See pages 50-52.)