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mediately cuts off the inverse code in the intervening blocks to the rear of the home signal.

On parallel tracks controlling traffic in the same direction, approach lighting is provided through the use of inverse code on one track only, the other track cutting off the inverse feed upon a train entering the parallel track circuit. At interlockings, when any reverse move is set up against a home signal, the code is cut off to the rear of the home signal, resulting in the rear home signal being put at stop. Under these conditions a 75 rate follow up code is automatically applied at the rear home signal in lieu of the inverse.

Where applicable the combination of half-wave feed track circuits together with an emergency a.c. power supply has a number of advantages when used with coded track circuits, which may be briefed as follows:

(a) The availability of an a.c. source with instantaneous reserve enables the primary of the track feeding transformers to be coded on tungsten contacts, the secondary of these track transformers being connected directly to the track through rectifiers. The combination of 110 volts, low current and tungsten contacts is very favorable to extended contact life and eliminates any contact resistance from ever being a factor.

(b) As previously mentioned, the track relay is not selected when inverse code is applied, as the energy by-passed by the track relay is not as important a factor as when battery is used. The system above described has no contacts in the forward code track circuit, and the only contact in the reverse or inverse code circuit is that which is used to select the pickup of the inverse track relay.

(c) Coded track circuits inherently have high broken rail detection and train shunting. The use of rectified feed to the coded track circuit provides high safety factors, as previously explained in reference to the application of half-wave rectifier feed to steadily energized track circuits.

(d) The use of rectified energy with coding of the primary permits high current energy on individual low ballast track circuits without contact difficulty or power supply limitations.

(e) It has been shown by test that coded half-wave track feed energy as set to operate the code following track relay, is of proper intensity to operate the conventional cab signal.

In conclusion, the use of rectified track circuits together with an emergency a.c. power supply in many applications of coded track circuits, has definite advantages from the standpoint of reliability, low power cost, economical maintenance, increased life of apparatus and ability to handle track circuits of exceptionally low ballast resistance.

Application of Code Principles to Signaling

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Let us attack this subject in accordance with the following general plan. We shall deal first with the steady energy method of signaling which was in universal use in the 20's previous to the development of the code system. Then we shall outline some of the main steps and problems in the development of the code principles and their application to

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practical signaling systems. We hope to do this in such a way that those of you who may not have been intimately active in the program may understand some of the problems, and realize some of the accomplishments that were associated with these very important developments. Because of the fact that the development of code systems was made possible by contributions from many people with the railroads and the manufacturers, it is not within the scope of this paper to give individual credit for each of the main features developed.

A general background may be established by considering the situation in railway signaling which existed in the early 20's. At that time I.C.C. orders were issued, requiring many of the leading railroads of the country to install some form of automatic train stop or train control. The signaling at that time was of a kind which we now refer to generally as the steady energy type, with signal indications displayed in accordance with the positions of the track and line relays. The source of power was either d.c. or a.c. One of the principal considerations before signal engineers at that time was the development of a system of signaling that would involve no moving parts. It was thought that such a system would eliminate the problems due to mechanical troubles, contact erosion, etc. It will be interesting for you to keep in mind this desire on the part of many of the signal engineers as this paper proceeds. There were two main schools of thought at the time in regard to the best method for complying with the orders of the Interstate Commerce Commission. One school advocated the intermittent automatic stop system, and the other continuously controlled automatic train control or speed control. In this paper our discussion in regard to engine-carried equipment will be confined to the use of cab signaling or train control, because it was to these forms of signaling that code principles were applied.

Track and Loop System

With the cab signal system applied to a railroad with relatively dense traffic, it is desirable to receive two or more proceed indications from the track. A few installations on territories having relatively light traffic have been in service with only one proceed indication. Initially, the track and loop system was installed extensively and gave quite satisfactory performance. This was what could be termed a two-element system, in which each element on the locomotive was energized as a result of alternating current flowing in the rails. The track element was energized from track circuit current flowing in one rail in the one direction, and in the other rail in the opposite direction. The loop element was energized by rail currents flowing in the same direction in both rails and returning over a line wire paralleling the track. There were two receivers on each locomotive, the track receiver being mounted at the front of the locomotive and the loop receiver usually mounted near the rear of the locomotive or tender. A difficulty encountered with the track and loop system was the interference from paralleling power lines disturbing the normal operation of the loop element of the system. The situation became troublesome, particularly to the installations which passed through metropolitan centers.

There was then a period during which special forms of receivers were designed, generally known as "immune" receivers, the main object of the design being to have the loop receiver so it would respond efficiently to the normal loop currents, and be relatively immune to the inductive fields produced by paralleling power lines. This remedy was effective on several installations, but was not effective enough for others, particularly those in the eastern part of the country. The next move was to change the frequency from 60 cycles to some other frequency sufficiently far removed from 60 that practical filters could be used to establish selectivity between the signaling frequency and the 60-cycle power lines. After considerable experimentation and study, the decision was made to use 100 cycles as the preferred frequency for train control and cab signaling on those installations where a survey indicated the necessity for a frequency other than 60 cycles.

Electric Propulsion a Problem

There were some electric propulsion railroads included in the I.C.C. orders and the track networks of these systems resisted all practical attempts to confine the loop current to its own particular track circuit. It was the electric propulsion railroads that proved to be the real hurdle that the track and loop system could not pass. The studies which were directed to the development of a system that would provide two or more indications on an electric propulsion railroad took into account the desirability of arriving at a system which would be universal in application; that is, would perform satisfactorily on either electric or steam propulsion tracks and would have a safe immunity to interference from paralleling power lines. The performance of then existing systems indicated the track element of the system was relatively much more immune to interference, and, in general, had better performance than the loop element. Accordingly, the attention of various inventors in the field was directed to expanding the scope of the track element so it would be capable of handling at least two proceed indications. Some consideration was given to systems employing two and three frequencies, but these were discarded as being of the last resort type of solution. The desirable solution was recognized as a system which would require only one frequency for its operation.

Active thought was then directed to the changing or modulating of the track current in two or more characteristic ways such that each could be detected safely by the engine-carried equipment. Early in this work the modulating or changing of the track current was referred to as "coding". Various types of coding were considered, such as time code, count code, etc. As this development study proceeded, the preferred method was to interrupt the track circuit current at different rates. A characteristic rate of interruption was, therefore, assigned to each of the proceed indications to be transmitted from the wayside system to the engine-carried equipment The engine equipment was visualized as consisting of a receiver mounted in front of the front wheels of the engine, and an amplifier circuit as described previously terminating in a code following relay. The contacts of this relay would then operate in an electrical generating circuit to derive a frequency corresponding to the rate of interruption of the track circuit current. These general principles were well analyzed and there was general agreement among those devoting their attention to the problem, but for quite a period of time there was no practical combination of apparatus to accomplish these results. The interruption of the track current at slow rates was desirable from the standpoint of life of the contacts that interrupted the circuit, but high rates of interruption appeared to be essential in order that good selectivity could be obtained between the various codes by the engine-carried equipment. During this period the solution to the problem appeared to be the use of slow rates of interruption for the track current in conjunction with some form of frequency multiplication in the engine-carried equipment before passing through the actual selectivity circuits.

Practical Solution Obtained in 1926

Tremendous effort on the part of engineers was concentrated on this problem, and it was in the year 1926 that the practical solution was obtained. This consisted essentially of the tuning of electrical circuits to the very low frequencies of two and three cycles per second, then rectifying the low frequency thus selected for the operation of a d.c. relay. It was an important discovery that it was practical to tune frequencies in this very low range and obtain selectivity which was satisfactory and compared favorably with that obtained with higher frequencies. The various elements which entered into the tuned circuit were chosen in such a way as to obtain the best practical selectivity. These included operating the copper-oxide rectifier at the most advantageous match and current level, and a similar choice was made in the magnetic materials used in the reactor of the circuit. The basic principles determined by these studies have continued since that time in all coded cab signaling, train control, and coded wayside signaling. One of the main modern developments of this principle has been the success in arriving at a practical means for tuning a circuit having a frequency of only 1 1/3 cycles per second.

As you know, following the completion of this development program, the main points of which have been outlined briefly, these principles were employed in actual installations involving many motive power units (electric, steam, and Diesel) and several thousand miles of track including a.c. and d.c. electric propulsion territories. One installation actually involves both d.c. and a.c. electric propulsion in the same territory.

It is interesting at this point to note the contrast between the resultant system, wherein indications are provided by measuring the rates of operation of moving parts while the ideal toward which some of the signal engineers were striving was to have a signal system with no moving parts. There have followed, since the initial installation of the code equipment, development studies concentrated on contact materials, arc suppression, and spring materials which have produced code-following apparatus with a life approaching that of the earlier types of signal apparatus.

Regarding Wayside Circuits

By the end of the 20's the railroads had complied with the I.C.C. orders of 1922 and 1924, and the following general situation existed. There had been very little change made basically in the wayside circuits, except what was necessary to provide the a.c. in the rails, with the proper characteristics to transmit the wayside indications from the track to the engine-carried equipment. The general arrangement, where the wayside signal system was modified as little as possible to permit the proper operation of cab signaling or train control, was known as "superimposed cab signaling or train control."

In the early 30's study was directed to applying the code principles to wayside signaling. These studies soon indicated the practicability of using a coded track circuit for the control of wayside signals and. thus, derive a wayside signal system that would be suitable with little or no change to transmit the wayside indications from the track to the engine-carried equipment. A wayside signal system of this type was visualized as consisting essentially of a set of equipment at the entrance to each block, which would be similar in many respects to the standard engine-carried equipment, except the code following relay would operate directly from the track instead of through the receiver and amplifier of the engine equipment. As the study progressed, it became more evident that such a system would be straight-forward, and would have important economical factors in its favor, particularly if there were sections of the railroad where new signaling was to be installed or the existing signaling was to be changed.

One of the main advantages seen for coded wayside signaling was the elim-

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ination of line wires for the control of the signals. The fact that line wires were in place on the existing signaling installations made it seem somewhat difficult for the code system to get a start. But, at about the time signal people were wondering where would be the first large application of the coded wayside signal system, there was a stretch of several hundred track miles of steam propulsion territory that was to be electrified. The revisions planned for the signal system were so extensive that it became entirely practical to consider the use of the coded wayside system. There was another problem, however, requiring solution, and this was to develop in the system an immunity to 25-cycle propulsion current comparable to or better than that which was provided by the centrifugal track relay that was the standard piece of apparatus used in the steady-energy signal systems to provide satisfactory performance in 25-cycle propulsion territory. The centrifugal relay, being essentially an induction-motor instrument, had immunity to the propulsion current because the 25-cycle energy could not operate the rotor at a great enough speed to close the relay contacts. The signaling frequency used on 25-cycle propulsion roads was either 60 or 100 cycles, which would provide the additional speed required for the proper operation of the centrifugal relay.

Courage was required to consider the discarding of such a well-established and thoroughly-proved device as the centrifugal relay. The continuing studies indicated such important advantages for the coded wayside signal system that it was considered desirable to develop an arrangement which would permit satisfactory operation in electrified territory with 25-cycle propulsion. The general principle which was adopted was to place a filter between the track and the code-following track relay that would pass the signaling current readily, but would reject the propulsion current. This general principle was never acceptable for the steady-energy signal systems, because there was always the possibility of an unsafe relay operation, due to one or more defects in the filter permitting the relay to be energized by the propulsion current. With the code system, however, this same condition would result in the steady energization of the code-following track relay and, of course, this would result in a restrictive failure. Therefore, the failure of a filter if used as the main element to obtain selectivity against the 25-cycle propulsion current would be on the side of safety for the code system, but could be on the unsafe side in the steady energy system.

After completing an extensive development program, both in the laboratory and on the railroad, there was a meeting in the office of the chief signal engineer of the railroad to make a final decision in regard to the type of system which would be used for the control of both wayside and cab signals for this very important stretch of a.c. electric propulsion railroad. There were several representatives of the railroad and of the manufacturing company present for the purpose of discussion previous to arriving at the decision. The decision was made in favor of the coded wayside signal system, and those who were present will probably never forget the closing remarks of the senior signal officer of the railroad in termination of this meeting, which were essentially as follows: "Boys, we have made a decision today that will be important in the history of signaling. I expect to retire soon, and I am hopeful that it will be a peaceful occasion. Therefore, I place this installation in your hands and ask you to make sure that I do not go out with a tin can tied to my tail." The excellent performance of that installation and others which have followed it are working monuments to those who made the important decisions at the beginning of the code system program.

It appears desirable at this point to mention a few of the outstanding advantages of the code system as recognized at that time:

(1) The engine equipment was more simple and straightforward than any other system which would display an equal number of indications.

(2) The safety of the overall system had been raised to the highest plane that had ever existed in signaling.

(3) There was improved performance relative to previous systems, particularly during adverse weather conditions when the line wires of the steady energy systems might be disrupted.

(4) The system was universal in its application to steam and electric propulsion territory, so the maintenance people would not have to learn a new type of apparatus or system when shifted from steam to electric territory.

(5) The power requirements and other characteristics of the code-following track relay were such that it was practical to operate longer track circuits safely than by any other method.

Since the late 30's there has been an ever-increasing scope to the application of code principles to the solution of the problems involved in single-track signaling. The most recent and, certainly one of the most important applications of the code principle, has been in the handling of the signal controls for the single-track stretches in C.T.C. systems. The application of these principles has made it practical to install complete centralized traffic control systems without requiring the installation of line wires for the control of the signals. Still later developments have permitted the use of normally-deenergized track circuits for the purpose of economizing in the use of power in primary battery territory.

No discussion of the application of code principles to railway signaling would be complete without mention of the application to line circuits of Centralized Traffic Control. There have been several different types of code applied in C.T.C. work, such as the time code, polar code, and circuit code.

New Applications of Code Principles

There are the relatively new applications of code principles in the safety or unit carrier circuits and in the proximity detector. You may recall my talk to you a year ago in which mention was made of the safety or unit carrier apparatus which permits the control and indication of one or more vital functions over a pair of line wires which may at the same time be performing some other service. The installations of this apparatus have continued to increase, and I am glad to report that their operation has been very satisfactory. The proximity detector, which was announced recently, has three installations that are now in the process of construction.

Probably a good way to remember all of these applications of code principles to railway signaling is to visualize them as applied effectively on a given stretch of signaling, say one engine division of a single-track line. In accord with the modern trend there would be time code C.T.C. under control of the dispatcher who would be located at division headquarters. There would be several sections of C.T.C. line, all controlled over the one pair of wires by coded carrier. The track circuits would be of the coded type, with the various signal aspects displayed in accordance with the code frequency applied to the track. Coded cab signaling on the motive-power units would be an ideal way to comply with the new I.C.C. order to permit the trains to operate in excess of 80 m.p.h. If there should be a non-track circuited branch connected with the main line, there should be a safety control and indication for the signal governing entrance to the non-track circuited territory. This safety or vital control and indication can be obtained readily by means of the safety carrier apparatus. If there should be a railroad crossing or other section of track where it is not practical to install the conventional track circuit, the proximity detector may be used. Thus all of these forms of coding may be coordinated in one installation so that they work with one another to expedite traffic and to provide the highest degree of safety.

There appears to be no question that the application of the code principles is one of the main contributions made to railway signaling since the track circuit was invented.