The Direct Current Track Circuits on the Electrified Lines of the Swedish State Railways

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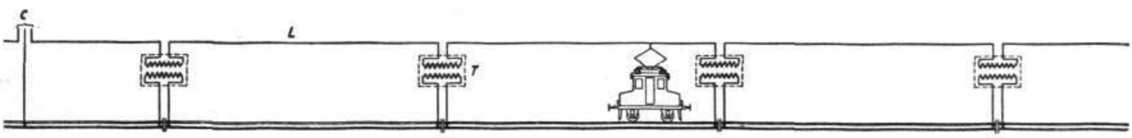
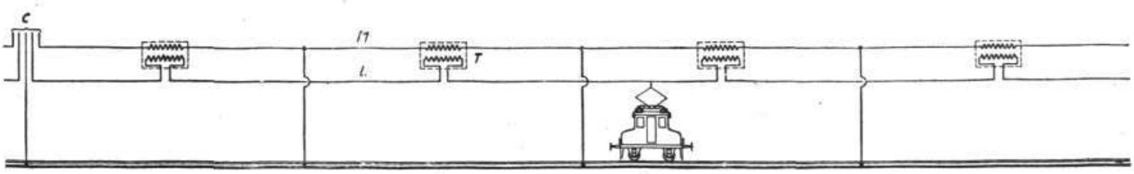
The first electrification scheme of the Swedish State Railways was completed in the year 1914 on a line of 123 km between Kiruna and Vassijaure an the Iron Ore Railways in northern Sweden. The electrification was extended few years later to cover the 304 km line between Kiruna and Luleå, making the whole of the ore traffic electrically propelled.

The power used is single phase alternating current of 15 cycles with a line voltage of 16 000 V. The return current from the locomotive to the transformer substations which are placed 40 km apart, flows through the rails.



X 7006 Fig. 1 a. C = from the substation; L = trolley-wire; T = booster transformer.



X 7007 Fig. 1 b. M = return conductor.

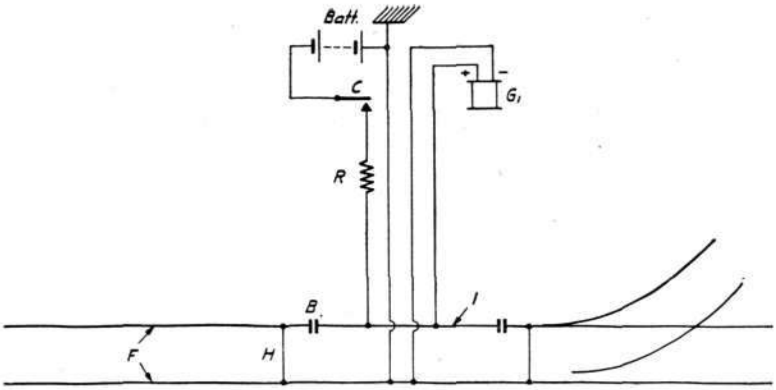
In order to reduce the inductance on adjacent telegraph and telephone lines booster transformers are provided, the secondary windings of which are connected in series with the rails, the primary winding being connected in the trolley line (Fig. 1 a). The windings have the same number of turns so that the current in the trolley-line and in the return rail will be the same.

The current in the rails causes a voltage drop along the track depending on the volume of the return current and the resistance of the rails. In a closed track circuit consisting of two parallel rails as outgoing and return conductors, this voltage drop arouses in the rails two mutually opposed EMF:s.

If the voltage drop in the two rails is different, which is always the case, if one of the rails is insulated at both ends so that the other rail alone acts as return conductor for the propulsion current, a foreign current is impressed on the track circuit and consideration must be given to this fact when designing the track circuit.

At the time of carrying out the electrification of the Iron Ore Railway, no other track circuits than the insulated rails in lengths of only about 20 metres existed on this line. These are used in Interlocking Systems in conjunction with lock-magnets on point levers as shown in Fig. 2 a or in conjunction with stick relays and route locking magnets on signal levers, the connection being carried out according to Fig. 2 b. The leads from the relay and the source of supply being connected to the track at practically the same point on the return rail, no disturbing voltage differences through the propulsion current in the rails were likely to occur, nor has any disturbance of this kind been experienced with the arrangement shown in Fig. 2.

Fig. 3 shows another arrangement with short



X 5011

Fig. 2 a.
B = insulated point;
C_1 = latch contact;
F = rails;
G_1 = point block relay;
H = cross bonding;
I = insulated rail;
R = resistance.

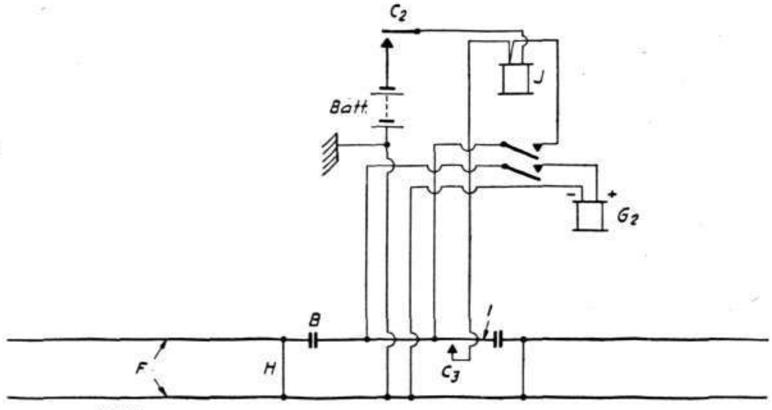
insulated rails, which on this railway line was brought into use for signalling the approach of trains at highway level crossings. The armatures of two combined relays *a* and *b* are mechanically interlocked so that the armature that first drops prevents the opening of the front contacts of the other armature. The arrangement is such that the interlocking does not release until both relay armatures have again been operated. The contacts on the armature of relay *a* (see Fig. 3) break therefore when a train passes in the direction *a* to *b*, and the contacts on relay *b* when a train passes in the direction *b* to *a*. A line circuit controlled by a front contact of relay is operated by trains that go in the direction *a* to *b* but is not affected by trains travelling in the opposite direction. No disturbing influence of the propulsion current on the relays can be observed with the arrangement described, evidently dependent on the fact that the rail conductors are too short for any voltage differences worth mentioning to occur.

The track circuit problem presented no real difficulties until the beginning of the electrification scheme of the 450 km line of State Railways between Stockholm and Gothenburg which was commenced in the year 1923 and was finished 2 years afterwards. On this line there were not only a number of short insulated rails of the same type as on the Iron Ore Railway, but also a large number of long track circuits, most of which were used for automatic signalling at road level crossings. These track circuits, which were provided with direct current relays fed from primary batteries, had in general a length of about 1 000 meters and could not without alteration be used in connection with electric traction because of the potential differences occurring on these lengths of rail attaining values high enough to disturb the functioning of the relays.

These track circuits were scattered along the line and generally at long distances from the stations, therefore the altering of the same to alternating current supply with frequency selective track relays of common type would have necessitated not only a replacing of the relays but even special equipment for generating and transmitting power for the feeding of the track circuits. It was therefore necessary from an economical point of view to find another solution.

The new electrification scheme was carried out with certain alterations concerning the arrange-

Fig. 2 b.
C_2 = contact on the signal lever;
C_3 = rail contact;
G_2 = route locking relay;
J = stick relay.



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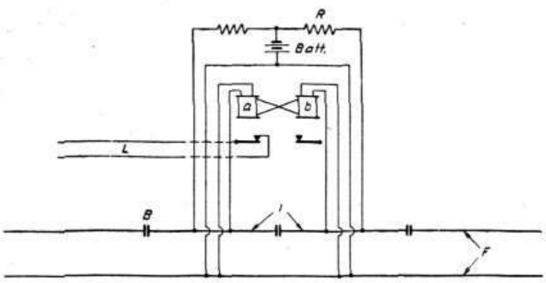


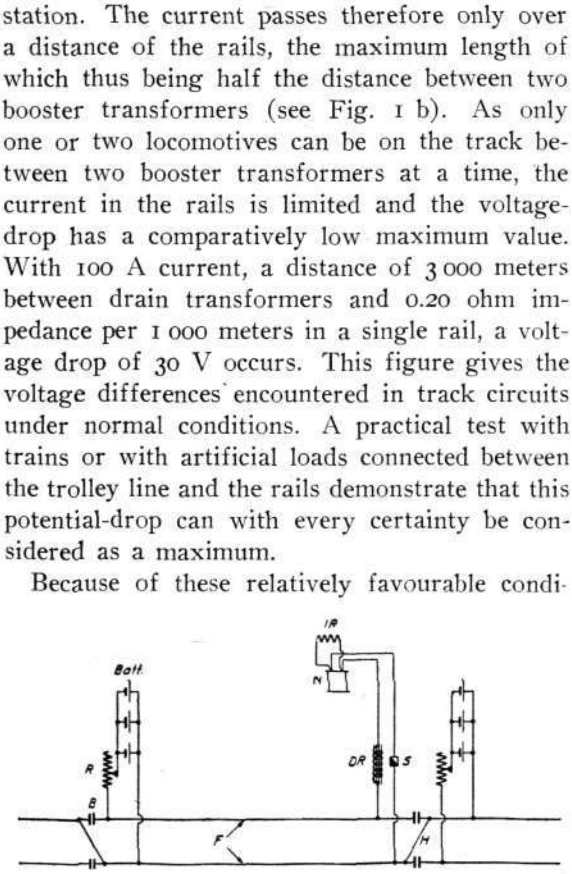
X 1052 **Fig. 3. L = line circuit.**

ment for the power supply. A special insulated conductor for the return of the propulsion current was fixed on the line poles parallel with the trolley line (Fig. 16). Booster transformers were still used, but with their secondary windings connected in series with the return conductor instead of the rails.

The return conductor was connected to the rails by special leads placed approximately half way between the booster transformers.

The return path from the locomotive is via the nearest of the above mentioned leads to the return conductor and then through this to the power station. The current passes therefore only over a distance of the rails, the maximum length of which thus being half the distance between two booster transformers (see Fig. 1 b). As only one or two locomotives can be on the track between two booster transformers at a time, the current in the rails is limited and the voltage-drop has a comparatively low maximum value. With 100 A current, a distance of 3 000 meters between drain transformers and 0.20 ohm impedance per 1 000 meters in a single rail, a voltage drop of 30 V occurs. This figure gives the voltage differences encountered in track circuits under normal conditions. A practical test with trains or with artificial loads connected between the trolley line and the rails demonstrate that this potential-drop can with every certainty be considered as a maximum.

Because of these relatively favourable conditions the thought occurred to try to retain the existing direct current line circuits and repell or divert the disturbing alternating current from the track relays by the device shown in Fig. 4.



X 1053 **Fig. 4. DR = damping resistance; IR = non-inductive resistance; N = track relay; S = fuse.**

Under steam working both rails were insulated, but with electrical propulsion only one of the rails could be kept insulated because the other rail must serve as a return conductor for the traction current.

To prevent leakage from one track circuit to the other, due to defective insulated points, steps shown in Fig. 4 were taken to lead over the return conductor from one rail to the other. Heavy cross bondings were provided at the ends of each track section for this purpose. If breakdown occurs in an insulated point between two rail conductors the cross bond will short circuit the rails in one of the track circuits thus making the fault apparent.

In series with the existing track relays which have a coil resistance of 4 ohm and approximately 0.1 A working current and were made according to the American Railway Associations specification a choking coil was inserted which at $16^2/_3$ cycles alternating current had a reactance of 450 à 500 ohm with voltages up to 200 V, but for direct current only 3 ohm resistance. Because of the insertion of this choke, the direct current voltage at the relay end must be raised from 0.4 to 0.7 V.

The relay coils were found to have a natural impedance of about 60 ohm at $16^2/_3$ cycles. The armature started to vibrate at an AC pressure of only 2 V corresponding to something above 0.30 A alternating current through the relay, should this, at the same time, have flowing through it a direct current corresponding to the release value of the relay. In order to produce the mentioned volume of current with the choke connected in series with the relay, an AC voltage of about 15 V is necessary.

Because the potential difference in the rails could exceed 15 V it was necessary to reduce the sensibility of the system to alternating current. This was attained by connecting in parallel with the relay coil a non-inductive resistance of approximately 30 ohm. Owing to this resistance, the consumption of direct-current at the relay terminals was increased by 20 %, so that the working current became 0.12 instead of 0.10 amps.

The necessary increase of voltage between rails at the relay end to compensate for this shunt resistance was only from 0.70 to 0.76 volts.

With alternating current, on the other hand, due to the shunt resistance, the impedance between the relay terminals was lowered from 60 ohm to about 16 ohm, so that an AC current of 0.12 amps instead of 0.03 amps was necessary to operate the relay. With the choke in series, a pressure of about 50 to 60 V would be necessary between rails instead of 15 V. This was considered to give absolute safety as higher voltages than 30 V were not encountered.

In order to prevent the breakdown of choking coils by momentary high voltages whereby a dangerous condition could occur, a heavy insulation was provided between turns as well as between the windings and the core. A factory test of 6 000 V was specified. The choking resistances was completely immersed in an oil filled iron box provided with substantial porcelain insulators for terminals.

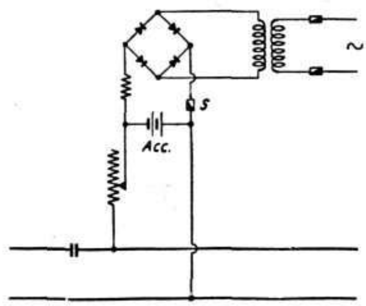
In order to protect the relay and the choking resistance from exceptional voltages in the return rail due to short circuit currents, which are always of short duration, and therefore in themselves not dangerous from a point of view of safety, fuses were put in the relay leads. Normal 1 A fuses were used at first. As in practice these were not found to have a mechanical strength, they were replaced with combined safety devices of the type often used for three phase induction motors consisting of a 6 A fuse and a thermic relay which operates when a load of 1 A is lasting for a few seconds.

As power supply for the type of track circuit shown in Fig. 4 a battery is used consisting of 6 caustic-soda cells with type Edison electrodes connected in series multiple 2×3. By using caustic soda cells type Le Carbone, which gives a higher potential, the number of cells can be reduced to 3 connected in 1×3. In certain cases where higher battery voltages are required six such cells have been used connected in 2×3.

The capacity of the battery for both types of cells is 1 500 Ah, which is sufficient for about 6 months working; battery renewals are therefore only necessary twice a year.

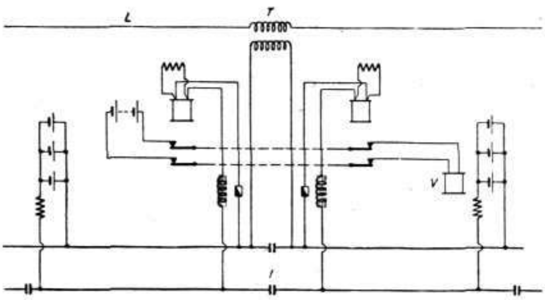
The series resistance at the battery is designed with a view to withstand the current which will pass through it on account of the voltage drop caused by the propulsion current. Fuses are therefore not put in at the battery end as it has been found that the cells will stand up to this current also.

In several cases where alternating current supply has been available the primary cells have been replaced by accumulators under trickle charging from metal rectifiers (Fig. 5). The accumulators act as reserve in case of accidental failure of the AC supply but in addition assists to deflect the propulsion current from the rectifier preventing the rectifier from being overloaded by the foreign current. The rectifier alone without a battery is not considered adviseable for the reason that the propulsion current in the track circuit could be changed into pulsating current that cannot be kept from the relay by the series choking coils.



X 1054 Fig. 5.

The number of track circuits of this category in use on the Stockholm—Gothenburg lines is about 140 quite a number of which have been in use for several years. The experience with them has been very favourable and has caused no apprehensions with regard to safety. In connection with the electrification now on hand on the lines Stockholm—Malmö, Falköping—Nässjö and Mjölby—Örebro, a further number of about 300 track circuits will shortly be equipped with the arrangement shown in Fig. 4. The favourable experience gained on the Gothenburg line gave rise to the arrangement shown in Fig. 4 being introduced on a number of track circuits on the Iron Ore Railway, although the voltage differences with the return system in use there was found to be greater than in the Gothenburg line. As the secondary windings of a booster transformer could not be connected in series with a track circuit (see Fig. 1 a) it was found necessary on the Iron Ore Railway to divide those track circuits in which an insulated point for a booster transformer was situated into two, one on each side of the booster transformer, and to repeat the track relays with a common line relay as shown schematically in Fig. 6. To avoid a line relay, by allowing the contacts of one track relay to break the current from track battery of the other track circuit, was not suitable as in this case the propulsion current would pass through the relay contacts and injure them. Even with the working conditions existing on the Iron Ore Railway the arrangement shown in Fig. 4 has proved sufficient to prevent disturbances from the traction current.



X 1055 **Fig. 6. V = line relay.**

In order to examine the shunt value of a track circuit as shown in Fig. 4 we assume that the track relay has a working voltage of 4 V and a release voltage of 0.12 V. We assume a track circuit length of 1 000 meters, a DC resistance of 0.11 ohm per kilometer of track and also a ballast resistance of 5 ohm per kilometer of track under the worst conditions.

In an unoccupied track circuit there is required at the relay end

$e = 0.40 + (3 + 1) \times 0.120 = 0.88$ V.

$i = 0.120$ A,

and at the battery end:

$$p = 0.88 + 0.12 \times 0.11 + \frac{0.90}{5} \times \frac{0.11}{2} = 0.90 \text{ V.}$$

$$u = 0.12 + \frac{0.90}{5} = 0.300 \text{ A.}$$

With 1.30 V battery voltage the necessary limiting resistance

$$= \frac{1.30 - 0.90}{0.300} = 1.33 \text{ ohm.}$$

With the release current passing through the track relay the voltage and current at the battery end will be:

$$p_1 = 0.90 \times \frac{0.12}{0.40} = 0.27 \text{ V.}$$

$$u_1 = 0.300 \times \frac{0.12}{0.40} = 0.09 \text{ A.}$$

For reducing the pressure from 1.30 V at the battery to 0.27 V at the track there will be required

$$\frac{1.30 - 0.27}{1.33} = 0.78 \text{ A.}$$

In order to increase the current from 0.09 A to 0.78 A a shunt between the rails is required at the battery end of

$$\frac{p_1}{0.69} = \frac{0.27}{0.69} = 0.4 \text{ ohm,}$$

this being the shunt value at which the track circuit functions.

To determine the rate of immunity of the relay to alternating current tests have been carried out with the aid of the laboratory track circuit shown in Fig. 7.

M is a potentiometer consisting of an ohmic resistance and a sliding contact ring connected to the accumulator. By moving the contact ring, the pressure between the rails S_1 and S_2 can be adjusted to any value between zero and maximum battery voltage. In series with the rail S_1 is inserted the secondary winding of a transformer connected to a $16^2/_3$ cycles alternator *G*, the voltage of which can be regulated within wide ranges by alternating the excitation. The voltage produced by the generator in the secondary of the transformer corresponds to the voltage drop caused in an actual track circuit by the propulsion current.

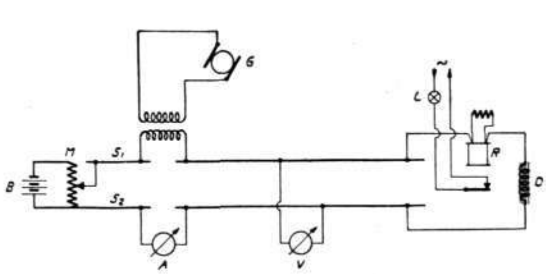
Between the rails S_1 and S_2 a relay *R* is connected provided with a 20 ohm shunt and a non-inductive resistance *D* of the type previously described. In the rail S_2 a moving coil ammeter A is connected and between the rails a voltmeter V.

A 220 V lamp M is connected over the front contact of the relay.

The following tests are carried out.

Test No. 1. The contact ring is set so that the relay operates whereupon the voltage is slowly reduced till the lamp *L* goes out. The ammeter indicates then the release current of the relay.

The alternator *G* is started and the voltage regulated till the relay armature begins to vibrate and the front contacts make, so that the lamp glows. The voltage is then read on the voltmeter which shows the disturbing alternating voltage



X 1056 **Fig. 7.**

required to operate the relay with the release current still passing through it.

Test No. 2. Whilst the alternator is at rest the contact ring of the resistance is set in such a position that the relay armature is attracted, i. e., the ammeter indicates the working current of the relay increased by the leakage through the 20 ohm relay shunt.

The alternator is then started and the voltage regulated till the voltmeter shows approximately the disturbing voltage read in test No. 1.

The contact ring on the resistance is then moved towards the zero position until the lamp *L* dies out completely; the alternator is then stopped and the ammeter read off. This shows the release value of the relay when the propulsion current is passing at the same time through the relay windings. The test is repeated with different voltages between the rails and the release values taken.

The tests 1 and 2 were carried out with relays of different designs and the results are given below:

A. Relay with 4 front and back contacts and the following current data with a 20 ohm shunt:

Working current 0.100 A
Releasing » 0.050 A

With test No. 1 disturbing pressure of 50 V was obtained and with test No. 2 a release current which varies from 0.035 to 0.040 A during the tests using a disturbing pressure from 60 down to 15 V.

B. Relay as above, but with only 2 back contacts and the following data with a shunt of 20 ohm.

Working current 0.100 A
Releasing » 0.050 A

Test No. 1 showed a disturbing pressure of 72 V and test No. 2 a release current of 0.045 A during tests with disturbing pressures from 72 to 15 V.

C. Relay of the same type with 4 front and back contacts but with large contact gaps and the following data with a shunt of 20 ohm:

Working current 0.130 A
Releasing » 0.050 A

With test No. 1 no disturbance occurs at 140 V (the maximum voltage of the alternator) and the release current in test No. 2 varied from 0.040 to 0.050 A at a disturbing voltage between 100 and 20 V.

D. Relay with 4 front and back contacts with small contact gaps and flexible back contact fingers and the following data with 20 ohm shunt:

Working current 0.110 A
Releasing » 0.035 A

Test No. 1 showed disturbance at 55 V and test No. 2 a release current which kept at a nearly constant figure of 0.035 A between 55 and 20 V.

From the tests made it is found that the amount of the disturbing voltage that can be allowed between the rails at the relay end without the functioning of the realy being upset, is to a considerable extent dependent on the design of the relay. The contact gap seems, according to the tests, to have a bearing on the sensitivity for alternating current, probably dependent on the bigger movement of the armature whereby the vibration is made more difficult. Further an increase in the number of back contacts makes the relay more sensitive to AC disturbances, evidently depending on the rebound against the back contacts which must be the more powerful, when a greater number of contacts are to cooperate.

Test No. 2 shows that the application of alternating voltage of the same value as the disturbing voltage according to test No. 1 generally causes a decrease of the releasing current, but this seems to keep within reasonable limits. The decrease in question appears to be least with relays with large contact gaps and few or flexible back contact fingers.

For the State Railway installations, relays have been used which are chosen for direct current operation without any consideration to the existence of disturbing alternating currents.

From the tests carried out with different relay types it was found that a more marked immunity to alternating current can be obtained with the arrangement shown in figure 4 by the choice of specially suitable relays for the purpose. Amongst other things an articulated finger design as now used on many modern direct current relays might offer certain advantage on account of the flexibility of the contacts which prevents rebounding and diminishes the tendency of the armature to vibrate under AC load.