SECT. II.—OTHER SELECTED PAPERS.

(Paper No. 4199.)

“Signalling and Interlocking of Keadby Deviation
Railway and Bridge.”

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REFERENCE has been made to the signalling question in the Author's Paper on “Keadby Bridge,”¹ but in view of the many special features involved in this work, and its probable interest to engineers, a detailed description of the undertaking is presented in the following Paper. As the principal engineering feature of the railway is the lifting-span of the combined rail and road bridge above referred to, which crosses the River Trent, the signalling problem at this point involved the consideration of three classes of traffic, viz., road, rail and river. Consequently, when the power equipment of the bridge was under consideration, and the necessity arose for putting down a special generating plant in connection with the electrical operation of the lifting-span, the question of all-electric signalling was brought to the front. Its adoption enabled the problem to be dealt with in a satisfactory manner, the three classes of traffic being co-ordinated in a general scheme of signalling, bridge-bolting and detecting, gate-locking and track-circuiting, the all-electric system being centralized in a 28-lever interlocking frame located in the bridge operating-cabin.

This frame is of the automatic indication type with lever-stroke completion. The movement of each lever requires manual operation only during the preliminary part of its stroke. After the completion of the movement in the function to be operated, the stroke is automatically completed, thus indicating that the function has worked correctly. The three-position upper quadrant signals adopted are the first to be installed in England as a complete scheme. The essential characteristics of three-position signals, as distinguished from lower quadrant signals now in general use, are illustrated in *Fig. 4*, and are dealt with in detail later.

¹ *Vide ante*, p. 33.

Among the special features of the work are the installation of an all-electric dynamic indication system for the operation of points and signals, the control of high- and low-voltage signals by track-circuit with overlap and non-overlapping sections, track-locking and detection of facing-points, indication in the cabin of the track-circuited lines, control of certain signals from mechanical cabins, and the electric control of mechanically worked switch-levers; bolt-locking and rail-detection of the lifting-span, road-warning and gate-locking, control of river signals, and the electric lighting of all signals, in addition to the control of the actual bridge-operation from the cabin. Reference to *Fig. 1* will show that one cabin is provided, situated in such a position on the east side of the bridge, adjacent to the heel of the lifting span, as to command a good view of the road, rail and river for the proper control of traffic. Special circuit-closers are provided for making and breaking the circuits across the lifting span.

The signalling control extends from Canal Junction on the west side of the River Trent to Gunhouse Junction on the east side, a distance of nearly $2\frac{1}{4}$ miles. Both up and down lines are track-circuited, including the portion of the track on the lifting-span, and suitably divided into the desired sections for the control of signals and track-locking of points, the whole of the track-circuits being indicated in the cabin. The gradient section of the line is shown in *Fig. 1*, on which it will be seen that the bridge is approached by rising gradients of 1 in 270 on the west, and 1 in 200 on the east side. As a protection against over-running of the signals when the lifting-span of the bridge is open for river traffic, sand drags are provided on both the up and down lines.

In the event of a train running past the signals (the sand-drag points being open), it is diverted from the running line into the drag, details of which are shown in *Fig. 2*, the friction between the rail and the wheels through the sand being sufficient to bring the train to rest without actually derailing it. The signals are lettered on the general diagram to agree with the numerical notation of their levers in the frame, whilst those signals which are controlled from adjacent cabins are denoted by letters.

On the east, the sand-drag points are controlled by lever No. 22, whilst Nos. 27 and 28 are the Down Inner and Outer Home signals respectively. The 45° and Stop positions of signal No. 27 are controlled from the cabin and by the track-circuit between it and the west end of the overlap beyond Starting signal No. 26, and the 90° position is controlled by the Starting signal in the 90° position. The 45° and Stop position of No. 28 is controlled from the cabin

Fig. 2.

and by overlap track-circuit to the west end of the platform, and the 90° position by the Inner Home signal No. 27, in the 45° or 90° position. The signal marked "Z" on the diagram is the Starting signal for Gunhouse Junction, and is operated by a circuit-closer on a mechanical lever in that cabin, and controlled in the 45° position by track-circuit to the Inner Home signal No. 27, and in the 90° position by sand-drag points No. 22 Normal, both Signals 27 and 28 being in the 45° or 90° positions. An electric lock controlled by the track is provided on this signal-lever to prevent its operation should the track be occupied between this signal and the Inner Home No. 27, the object being to prevent the release of the mechanical Distant signal-lever with signal "Z," at "Danger," but its lever reversed. Signal "Z," which is not controlled from the bridge-cabin but from the Gunhouse Junction box, is for economical reasons a low-voltage operated signal, the movement being worked from a small accumulator at the base of the post. A signal repeater is provided to show its operation, and the track-circuit to the Inner Home signal No. 27 is indicated in Gunhouse Junction cabin.

On the west side of the river, the 45° and Stop positions of the Down Starting signal No. 26 are controlled from Keadby bridge cabin, and by track-circuit to the Down Inner Home signal at Canal cabin, and the 90° by a relay operated from the Canal cabin, and energized by the lowering of signals R, S, T and U. On the Up line, sand-drag points No. 11 are provided to give protection similar to that previously described with reference to No. 22. A cross-over road and a connection to Hart's siding are worked by levers in a mechanical ground-frame controlled by electric locks released from the bridge cabin by levers 7 and 8 respectively. Lamp indicators at the ground-frame are provided to show when a release has been given.

On the Up line, a low voltage signal A is the Starting signal for the Canal cabin, and its control is similar to that described for signal Z on the Down line. The 45° and Stop positions are controlled from Canal box, and by track-circuit to Inner Home signal No. 2, and the 90° position by sand-drag points No. 11 Normal, both signals Nos. 1 and 2 being in the 45° or 90° position. The 45° and Stop positions of Outer Home signal No. 1 are controlled from the cabin and by overlap track-circuit to the Starting signal No. 3, and the 90° position is dependent on Signals 2 and 3 being in the 45° or 90° position. The 45° and Stop positions of the Inner Home signal No. 2. are controlled from the cabin, and by overlap track-circuit to a point 440 yards east of Starting signal No. 3, and the 90° position by signal No. 3 being at 45° or 90°. The

Starting signal No. 3, 45° and Stop positions are controlled from the cabin and by track circuit to Gunhouse Junction Inner Home signal, and the 90° position by the operation of a relay from Gunhouse Junction cabin energized by the lowering of signals H, J, and K.

The controlling arrangements for the lifting span of the bridge are necessarily of a complicated nature, for the reason that it has to be bolted at the nose end and the correct alignment and level of its rails with the rails on the fixed spans ensured by their being plunged at right angles and detected, both at the nose and heel, before rail or road traffic can pass over the bridge. Nos. 16 and 17 are the rail-detector levers for the west and east ends of the bridge; No. 18 is the bridge-bolt.

For the protection of the road traffic a pair of electrically-worked gates are provided at the east side of the bridge (Fig. 3), and on the west side one hand-worked single gate. The reason for the provision of a hand-worked instead of an electrically-operated gate on this side was owing to the prevalence of fog at certain seasons of the year, which would render the safe working of road traffic somewhat problematical if controlled entirely from the bridge cabin, the distance from the west gate therefrom being about 200 feet. The gates on both the east and west sides are locked or released by stops electrically controlled from the cabin by lever No. 15. Road-warning signals (lever No. 14) are given from the cabin by means of electric bells

on the road approaches at each end of the bridge. The cabin controls the operation of signals (lever No. 5) for the conduct of river traffic by a special arrangement and location of lights (as shown in *Fig. 3*), certain of these lights changing to different colours to indicate to ships at night the position of the lifting-span either "Up" or "Down." In the daytime a hand-worked ball signal is used for the same purpose.

The normal position of the lifting-span is down, i.e., "Right" for the railway and road traffic. The sand-drag points Nos. 11 and 22 are in their normal position for running lines, the bridge-bolt is in, and the rails plunged, allowing under these conditions the signalled movements across the bridge and the approach of trains from either direction, in addition to vehicular and pedestrian traffic.

To open the bridge for river traffic the following sequence of movements of the levers above mentioned takes place, ensured by ordinary interlocking. The road-warning lever No. 14 is pulled, causing a bell to ring at each of the warning signs. This bell continues to ring until the gates are nearly closed across the roadway, when the circuit is interrupted, and the ringing ceases. These signs are illuminated at night, displaying the word "Danger." Lever No. 15, released by No. 14, is then pulled to operate the gate-stops and release the electrical operating-lever in the signal-cabin to allow the gates (east) to be worked. A bell is also rung at the gateman's hut as an indication to the gateman to close his gate. Each gate now being in its reversed position across the roadway, the gate contacts are made, and the east gate controller-lever being put back to its normal position, an automatic return indication movement is given to lever No. 15 as an assurance of correct working.

Sand-drag levers Nos. 11 and 22 are then pulled, thereby opening the points to the sand-drags in the Up and Down roads in the facing direction of traffic on each side of the bridge, and an automatic return indication movement given on their levers denoting the correct working of the points. This effects the release of levers Nos. 16 and 17, which, on being pulled, operate the rail-detectors at the east and west ends of the lifting-span. The rail-plungers are withdrawn from the rail-ends, and such withdrawal electro-mechanically detected. At the same time the contacts of the bridge-circuit closers are broken. The correct working of the operative connections having been obtained, indication is given to levers Nos. 16 and 17 by the automatic completion of their stroke.

As soon as the levers Nos. 16 and 17 have been correctly worked, a release is effected on the bridge-bolt lever No. 18. This lever when pulled makes suitable contact to allow the current to operate a series of clapper-switches at the cabin, through the contacts of which current passes to the motor for withdrawal of the bridge-bolt. The proper working of the operative parts having been ensured, a return automatic indication movement is given to the operating-lever No. 18.

The last operation necessary before the actual bridge-operating mechanism is free to be used is the pulling of a king-lever, No. 19. This lever is released by the proper working of lever No. 18, previously described, and when pulled, energizes a relay, through the contacts of which the high-voltage current (220 volts) for working the bridge-motors passes to the clapper-switches of the master-controller; at the same time an electric lock on the master-controller handle is released, so freeing the latter for the operation of the bridge through the dependent mechanism described in the "Keadby Bridge" Paper. Immediately the controller-handle is moved from the normal position the king-lever is locked in its pulled position, thus providing the necessary interlocking between the frame and the bridge-operating gear.

Before the interlocking frame can again be brought into use, lever No. 19 must be restored to its normal position, and this can only be accomplished when the leaf is down on its bearings and a contact on the extreme point of the lifting-span is closed in series with other contacts on the lock in the master-controller. The function of the latter contacts is to ensure that the controller is locked in its normal position. To lower the bridge for normal traffic, the sequence of movements of the above-mentioned levers is reversed.

Three-Position Signals.—The use of three-position upper quadrant signals presents many interesting features, and the following is a short description of their mechanism and control:—Referring to *Fig. 4*, each signal works to three positions in the upper quadrant, which is sound practice, as gravity exerts its force to bring the arm to the "Danger" or "Stop" position in the event of any disconnection of electric control or breakage of operating connections.

The horizontal position, and a red light at night, indicates "Stop."

The intermediate or 45° position, and a yellow light at night, means "Proceed, prepared to stop."

The vertical, or 90° position, and a green light at night, means "Proceed."

It will be seen, therefore, that three distinct instructions are

Fig. 4.

THREE-POSITION SIGNAL.

BY DAY, ARM HORIZONTAL.
BY NIGHT, A RED LIGHT.

{ ARM RAISED TO A POSITION
BY DAY, { MIDWAY BETWEEN HORIZONTAL
& VERTICAL.
BY NIGHT, A YELLOW LIGHT.

BY DAY, ARM RAISED TO VERTICAL
POSITION.
BY NIGHT, A GREEN LIGHT.

**ORDINARY MECHANICAL
SEMAPHORE SIGNALS.**

**DANGER
STOP.**

BY DAY, BOTH ARMS HORIZONTAL.
BY NIGHT, TWO RED LIGHTS.

**CAUTION.
PROCEED CAUTIOUSLY.**

BY DAY { TOP ARM LOWERED.
BY NIGHT { BOTTOM ARM HORIZONTAL.
{ TOP LIGHT GREEN.
{ BOTTOM LIGHT RED.

**ALL RIGHT
PROCEED**

BY DAY, BOTH ARMS LOWERED.
BY NIGHT, TWO GREEN LIGHTS.

given to the driver by the use of one arm, the position of each arm at 45° being governed by the signal-cabin and track-circuit and the signal ahead at the "Stop" position. The 90° position is auto-

matically assumed when the signal or signals ahead are at the 45° or 90° position. The governing of the different positions of the signals A, 1, 2 and 3 has been already referred to. Signals A and Z not being controlled from Keadby bridge cabin, low-voltage signal movements are used. The only differences between these

Fig. 5.

low-voltage machines and the 110-volt machines used in connection with all signals controlled by the bridge-cabin are in the motor, and the elimination of the device for generating dynamic indicating current after a signal-arm has been returned to "Danger," the signal-lever still being in the reversed position, and the addition of special means of holding the signal-arm in the desired position.

The two types of high and low voltage top-mast mechanism used at Keadby bridge (*Fig. 5*) have the same general outside appearance.

The cast-iron casing, or housing, and the method of attachment to post, train of gears, driving-shaft and coupling, spectacle-shaft and circuit-controller are all common to both.

Dealing first with the low-voltage signal movement (*Fig. 6*) and its application to signals A and Z, the mechanism has been designed to obtain great freedom of operation in the gearing between motor and movement. The gear-teeth are heavy, and ample clearance between the teeth ensures a free movement of the gears under all conditions. The motor operates in a dust-proof casing, and is directly connected to the spectacle-shaft by means of the train of gears placed in the compartment at the back of the case; a special coupling allows for any variation in the alignment of the driving- and spectacle-shafts, and also provides effectual locking of the signal-arm in the "Stop" position to prevent any unauthorized movement. The direct-current motor in this, and also the 110-volt type, presents a common feature for checking the motion of the signal-arm. The signal-arm, when going from the 90° to the "Stop"

Fig. 7.

position, causes the motor to rotate in the reverse direction, thereby generating a current which very effectively checks the motion of the signal-arm when the motor is shunted through a snubbing resistance just before the arm comes to the "Caution" or "Stop" position. A friction-clutch between the motor and its driving-pinions protects the motor and gearing from the effects of sudden strain. A device contained in a casing forming part of the clamp-bearing serves as a shock-absorber, and affords means of a proper signal-adjustment.

The circuit-controller B, shown in *Fig. 6*, is an important part of the signal mechanism through which the motor and signal circuits are controlled. It consists of a frame carrying a specially-treated hardwood cylindrical drum on which contact plates are mounted; adjustable contact fingers, with an attachment for locking them in proper position, an attachment for producing snap contacts when required, and segmental gears by means of which the movement of the main shaft is transmitted to the circuit-controller.

The motor is of the four-pole series-wound type. A retaining device for holding the signal in the 45° or 90° position is shown in *Fig. 7*. *Fig. 8* shows the general arrangement of circuits for signal A, with the method of its operation from the Canal cabin by means of a circuit-closer on a mechanical lever and its control by a repeater track-relay and 90° position control by a repeater relay

at the signal, which relay is governed by track relays and signals 1 and 2. The track-circuit repeater relay is wired as a stick relay through a lever contact to ensure that, after the signal has been put to "Stop" and a train has passed clear of the track-circuits governing the signal, the signal will not clear again automatically. The stick relay governing the operating-circuit will not pick up until the signal-lever has been put back and the track cleared.

The 110-volt top-mast mechanism (*Fig. 9*) is used for Keadby bridge cabin signals 1, 2, 3, 26, 27 and 28. This mechanism is provided with a four-pole series-wound motor, but differs from that of the low-voltage movement, inasmuch as the armature constitutes the means for holding the signal in the 45° or 90° positions. The surfaces of two of the pole pieces are serrated so that, when the holding field windings are energized, the magnetic attraction between these two-pole pieces and the armature prevents rotation of the armature in either direction and holds the signal in the desired position. The high resistance of these windings reduces the current to a minimum. A dynamic indication-current is generated by the over-run of the motor when the signal is returned from the 45° or 90° to the "Stop" position for the purpose of completing the return stroke of the operating-lever in the cabin,

Fig. 8.

which feature is specially described hereafter. When a train has

entered a track-section governed by the signal, the track relay is

de-energized, thereby breaking the operating and holding circuits of the motor and the signal-arm returns to the "Stop" position. A spring attachment is used in connection with the driving-shaft, which stores up the energy necessary to produce the dynamic indication, when the signal-arm is in the "Stop" position. The coupling between the driving-shaft and the signal-arm has an initial free movement, during which the springs are put into tension, after which the arm commences to move to the "Proceed" position. On returning the arm to the "Stop" position, if the lever has not been put back by the signalman, the energy stored up in the spring is retained until this is done by him, when it is released to produce the power necessary for the indication. These springs have no effect in restoring the signal-arm to the "Stop" position.

In both the mechanisms described in *Figs. 6 and 9* friction-clutches are provided between the motor and its pinion, and to prevent injury to the motor in the event of any derangement of the circuits, a safety device consisting of a pawl and ratchet-wheel arrangement in combination with a brake is fitted between the second intermediate wheel "F" and its pinion "G." *Fig. 10* shows the general arrangement of circuits for signal No. 1, the 45° and "Stop" positions being controlled from the cabin and track-relays, and

Fig. 10.

the 90° automatically through the circuit-controllers on signals 2 and 3. This circuit is typical of the other signals controlled from this cabin.

Interlocking Frame.—For the operation of the signals, points and special apparatus peculiar to the bridge protection, an inter-

Fig. 11.

locking frame of twenty-eight levers is provided in the cabin. Of these, six levers are used for the Up and Down line signals: two for the sand-drag points, two for bolt-locks to cross-over and siding connections, one for each of the rail-detectors, east and west, one each for the bridge-bolt, king-lever, road warnings, gate-stops and

Fig. 12.

river signals, whilst the remainder are spare spaces. The interlocking frame is designed with a view to the easy accessibility of all parts from the point of view of maintenance.

A side elevation is shown of the signal and switch levers in Figs. 11 and 12, and a front elevation and end view of the locking-

frame in *Fig. 13* (with the casing removed) show the relative positions of the operating-lever and contacts, indicating contacts, solenoid indication magnets, relays and terminal board. The framing consists of cast-iron standards, front and back tie-pieces, and, together with the locking-boxes, is built in sections of four or eight levers. The terminal and bus-bar board is placed at the lower back part of the frame, and all fuses and terminal posts are directly under their respective levers, and lettered for identification in accordance with the circuit plan. The lever-castings are screwed to the tie-pieces or bridges at 3 inches pitch. Electric locks on certain levers are provided, these being fitted upon the lever-cover, the lock engaging in a notch or notches cut in the upper edge of the lever-slide. The polarized relays, one for each lever-circuit,

Fig. 13.

are mounted in line upon a shelf at the back of the frame. These relays are provided with a soft iron magnet placed lengthwise between the poles of a permanent magnet, and are used for detecting the presence of foreign or stray currents in the circuits, and will be referred to later under "Cross Protection." The indication-selector, one for each switch-lever circuit, also mounted at the back of the frame, consists of a simple design of two electro-magnets and an armature fitted with contacts, these contacts being closed in one direction when the lever is reversed and in the opposite direction when the lever is normal.

Above the interlocking frame is a diagram of the track and signals, showing the tracks divided into sections which correspond with the track-circuit sections controlling the various signals.

Each section is clearly distinguished by different colours from the adjoining sections. In the centre of each section an indicator with one red and one white disk is fixed. These disks are eyeball shape, and are operated by an electro-magnet. The normal (energized) position of these indicators would show "White" with the track unoccupied, and "Red" (de-energized position) when the track is occupied by a train or vehicle or failure of current. With the aid of this diagram the signalman can follow the position of trains through the area within his control under all weather conditions.

The design of the interlocking frame and the controlling circuits presents several features essential to safety and facility of operation:—

1. Means are provided for checking the correspondence of movement between the lever and points, signal or other apparatus to be controlled. This is obtained by means of dynamic indication, the energy being furnished by a momentary dynamic current generated by the motor only when such points or other apparatus have been fully worked to their correct position and locked. The use of dynamic current prevents the chances of a false indication due to a cross between the wires of the circuit.
2. Means are provided for preventing unauthorized movement of points, signals or other functions through foreign or stray currents.
3. Means are provided for giving an automatic movement to the lever-bar, thereby completing its full stroke, and indicating the correctness of the movement freeing the locking for operation of dependent levers.

Taking the operation of switch-lever No. 11 (*Fig. 12*) as an example, it will be seen that the lever-bar A is provided with a cam-slot B, which transmits motion to a tappet for effecting the ordinary mechanical locking. By means of a slot C with right and left hand cam-faces D and E, an automatic indication stroke is given to the lever by means of a solenoid magnet F, the connecting-rod roller G of which acts on the inclined cam-faces D and E for reverse or normal indication respectively. An extension of the lever-bar carries an insulated circuit-maker H, which makes and breaks contact with two pairs of normal and two pairs of reverse operating spring contacts K and K¹ and L and L¹ respectively. A pin M screwed to the top end of the lever-bar operates in a slot N of a movable plate O; to this plate an insulated circuit-maker P is

attached, so arranged that when the lever-bar is pulled the plate O is moved at the end portion of the stroke by means of the pin M and the attached circuit-maker P makes contact with the fixed indicator spring contact Q. The breaking of these contacts takes place upon the last portion of the automatic movement of the lever when going to reverse or normal. The points are unlocked, worked and locked by the switch and lock movement shown in *Fig. 14*, which is driven by a series-wound 110-volt direct-current motor. One normal and one reverse wire is used for the control; the normal control wire is also used for the reverse indication and the reverse

Fig. 14.

control wire for the normal indication. A main common wire is connected at each switch location.

The point-operating mechanism is contained in a weather-proof casing, and consists of the motor A, spur-gears B, friction-clutch C, main or cam-gear D, pole-changer E, switch drive-rod F, locking-bar G, and detector H.

Operation.—To reverse the points the lever-bar A is pulled the first portion of its stroke about 2 inches; this stroke is limited by the roller G of the solenoid connecting-rod butting against the vertical shoulder R of the horizontal slot C. Its effects:—

1. The preliminary actuation of the mechanical locking by means of the cam-slot B.

2. The making of the reverse operating-springs L, L¹ by the circuit-maker H.
3. The making of the indication-springs Q by the circuit-maker P.

Referring to the wiring-diagram (*Fig. 15*), the operating-circuit

Fig. 15.

is completed through the coil of the safety relay 1 (ensuring the breaking of the local indication-circuit through contact-springs 21 and 22), coil 3 of the selector relay (making contact with the springs 4 and 5), reverse contact spring 6, wire 7, coil 8 of pole-changer, contact 9 and back to battery by main common wire 10, thus completing one path of a circuit for holding the pole-changer contacts 11 in the position shown. The second path of a circuit from wire 7 passes through the contact 12, motor armature 13, contact 14, field-coil 15 and back to battery by main common wire 10. The completion of this circuit starts the motor. The facing point lock-bar is raised, the points unlocked, the points reversed and locked, the facing point lock-bar is lowered. The points are unlocked, the F.P. lock-bar thrown, the points reversed and locked. At the end of the stroke the pole-changer is tripped to the opposite position; this action breaks the motor operating-circuit and current ceases to flow through the safety magnet 1. The over-run of the motor

now comes into play and develops a momentary dynamic current in the indication circuit, the circuit being from the motor-armature, pole-changer contact 16, field-coil 15, return wire 10, polarized relay 17, safety relay-coil 18, selector relay-contacts

4 and 5, reverse contact 19 and wire 20 to the motor-armature. This completes the circuit to attract the armature 23 to close contact springs 21 and 22, thus setting up a local circuit from the battery through safety-relay contact-springs 21 and 22, indicator-spring contact N, solenoid magnet 24, back to battery. This circuit energizes the solenoid magnet, and the connecting-rod roller G (*Fig. 12*), acting on the cam portion D of the indication-slot C gives an automatic stroke to the lever-bar, thereby completing the stroke of the locking-tappet by means of the cam-slot B, and also breaks the local indication-circuit at the indication contact-springs N. To place the points normal, a similar sequence of movements takes place. Wire 20 becomes the normal operating-wire, and reverse operating-wire 7 becomes the return indication-wire; the eventual automatic normal movement of the lever being

Fig. 16.

given by the energizing of the solenoid magnet 24 bringing into play the operation of its connecting-rod and roller G, acting on the cam E of the indication-slot C.

Cross Protection.—For cross protection, a no-voltage release reverse current-breaker with its indicating red lamp and a polarised low resistance relay of a similar type to that inserted in each circuit governing a switch, signal or other function is provided on the operating switchboard. These relays are so connected that all working currents pass through the relay-coils in one direction to maintain a closed contact, whilst foreign or stray currents on the operating-wires pass through the relay in an opposite direction and cause the contact to open. This open contact breaks the control-circuit of the cross-protection circuit-breakers, and thereby opens and cuts the current supply to the system. *Fig. 16* shows a simplified circuit illustrating the principles of the cross-protection

system. In a signal operation, a dynamic return indication stroke of the lever is only given for the normal position of the signal, whereas a switch-lever is provided with dynamic indication for positions.

A switch-lever with its solenoid indicating-magnet, selector safety relay and switch and lock movement is utilized for the operation of the rail-plungers, detector-apparatus and bridge circuit-closers; the operating and dynamic indication-circuits are the same as described in connection with No. 11 point-lever. *Fig. 17* shows the general arrangement of the apparatus at the nose of the lifting-span. The first operation of the movement is to withdraw the detector-bolt A and break the circuit connections by

Fig. 17.

means of the bridge circuit-closers B, operated by rocking-shaft connection C.

The rail-plungers D, E, F and G are then withdrawn by rocking-shaft connections H, and a final movement of the detector-bolt A detects the proper reversal of the rail-plunger, and dynamic current is generated by the motor to give the necessary automatic indication-stroke to the operating-lever No. 16. An identical arrangement of apparatus is provided for lever No. 17 at the heel end of the lifting-span.

Fig. 18 shows a view of the bridge circuit-closer; three six-way and one ten-way types are used. The device consists of box A, with substantial contact jaws B, so adapted on a base-plate C as to

allow for a lateral movement not exceeding $1\frac{1}{2}$ inches. On the operating side a cast-iron box D is provided with contact-making blades E, and a centering device F. When the lifting-span is fully lowered, the centering device F is moved forward until the horns G and H ensure alignment of the laterally movable box A, further movement of the connection F by means of slot J of the contact-maker driving-rod K, butting against the shoulder of the centering device, forces the contact-making blade E to enter the contact jaws B. The full stroke of the driving member is about 13 inches.

River-Signals.—To control these, a signal-lever (No. 5 in the frame) is used, having a battery indication which is given on the normal

Fig. 18.

position only. The arrangement of lights (north and south) is shown in Fig. 3. On the west pier a fixed red light is provided. On the second pier from the westward, a 2-foot beacon ball being raised to the top of a 25-foot mast, indicates by day when the span is about to be lifted. A red light is shown on the centre-line of the pier at a height of 6 feet above the light on the nose end of the span, which changes to green when the lever is first pulled, and eventually to white through a contact on the limit switch when the span has attained the 45° position. The light on the lifting-span is a white light, but being shaded in the normal (down) position of the span by a red glass screen, it shows white only when the bridge is lifting or at rest in the lifted position. Two fixed red lights are

provided on the pier at the heel-end of the lifting-span. The lamps used are fitted with Fresnel lenses in all cases, and illuminated through an arc of 180° .

The lighting circuit passes normally through the back contacts of two de-energized relays, A and B. When the lever is pulled, the reverse circuit energizes relay A, and at the same time displays a sign "LIFT" to the ball-signal operator. The lighting circuit is now changed through the relay front contacts to light the "green" lamps. A tap off the reverse circuit passes to a contact on the limit switch of the lifting-span, and as soon as the contact is made at the 45° position of the leaf, the relay B is energized, and the lighting circuit is again changed to show white. The display of the white light on the pier by night with the white light on the lifted span, and the two fixed red lights on the pier at the heel end of the opening-span, indicates to river traffic "channel clear."

Placing the lever to normal, the red light is immediately displayed on the pier, and the sign changed for the ball-signal operator from "LIFT" to "LOWER." The span being fully lowered, the white light on the nose end is screened to show "red." A battery indication is established, passing through the indicator-magnet, indication-contact, and normal operating-lever contacts, back contacts B and A and ball-signal normal contact to complete the automatic stroke of the lever.

Current-Supply.—The 110-volt current supply for the signalling is obtained from one-half of the main battery (220 volts), which is used for supplying power to the bridge motors. Counter E.M.F. cells are installed to regulate the voltage on the signalling and lighting mains. The current supply for the track-circuits, indicators, etc., is obtained from a set of fourteen accumulators installed in the main battery house. This supply serves all the low-voltage circuits on the eastern side of the bridge. Two batteries of Tudor accumulators housed on the western side of the bridge are arranged to supply current at 110 and 25 volts. The 110-volt supply is for the roadway lighting, whilst the 25-volt supply feeds the track and low-voltage circuits on the western side between the bridge and the canal. A 25-H.P. petrol-engine, driving generators of 37, 175 and 110 volts on a single shaft, is used to charge the accumulators.

The engine is fitted with dual ignition, and is water-cooled. The 110-volt battery has a capacity of 460 ampere-hours, the capacity of the 25-volt battery being 280 ampere-hours. The 110-volt and

25-volt supply, if required, can feed direct to the interlocking and track-circuit feeds.

The signal Z at Gunhouse end of the installation is supplied with current from a set of Fuller accumulators which are connected across the low-voltage mains; this battery consists of six cells, giving 12 volts, and has a capacity of 30 ampere-hours. The voltage of the mains at the point of connection of this battery is about 14, and through a variable resistance is continually on charge at a rate about equal to the output during 6 hours. This arrangement allows a circuit of 2.2 amperes for 10 seconds available for clearing the signals, without causing an excessive drop of potential in the feeds.

Wiring.—The operating and control wires are run in grooved trunking laid in the 6-foot way where possible, to enable the sleepers to be removed without interfering with the wire run. Between the lifting-span and the cabin flexible conductors are used, made up into cables protected by cab-tire sheathing. These cables are so arranged that when the lifting-span is down they are carried in troughs constructed of angle-bars, and are lifted out in long and easy curves when the bridge is raised. The portions of the cables that have no movement are securely fastened to the bridge-girder by means of substantial cleats. The wires on the fixed span are carried in wooden trunking with the exception of those portions of the cross runs which are carried through the rail-supporting timbers. In these cases lengths of 3-inch substantial iron tubes, bushed with fibre conduit, are used. For expansion at all points where necessary, the trunking is allowed to move freely by sliding through boxes which contain the slack wire. All trunking over the fixed spans is carried upon wrought-iron brackets firmly secured to the structure by tapped bolts. Throughout the wiring care has been taken to avoid soldered joints, and to prevent slackening of terminal screws track-circuit connections are fitted with spring-washers. Main feed and return wires are used to supply the track-circuits with current from a central supply. These mains also supply current to the indicators, line and repeater relays, etc. Overhead wires carried on tall steel masts 110 feet above high water of the Trent serve to connect the signalling and telephone circuits on each side of the river when the lifting-span is raised.

The Author would like to place on record his appreciation of the valuable assistance rendered by the Company's Signal Superintendent, Mr. A. F. Bound, under whom the whole of the signalling

installation controlling the railway and the working of the bridge was carried out; also of the services of Mr. E. C. Irving, the Engineer of the British Pneumatic Railway Signal Co., Ltd., the contractors for the work, for the care and attention given to the novel and intricate problems which were met with and successfully overcome in completing the work.

The Paper is accompanied by seventeen sun-prints, from which the Figures in the text have been prepared.