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(54) IMPROVEMENTS IN OR RELATING TO IMPEDANCE BONDS

(71) We, WESTINGHOUSE BRAKE AND SIGNAL COMPANY LIMITED, a Company incorporated under the Laws of Great Britain, of 3, John Street, London, WC1N 2ES, England, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to impedance bonds especially but not exclusively for d.c. powered electric railways.

In the field of direct current powered electric railways, particularly at lower voltages in the range 500V.—3KV., traction currents may reach several kilo-amperes even in normal circumstances, while transient and fault currents may reach tens of kilo-amperes. Railway electric traction systems utilising the running rails for the passage of return current therefore preferably utilise both rails in parallel to carry the return current, so as to minimise resistance to the passage of return current (and also to reduce the stray ground voltages caused by current passing through the resistance of the rails). At the same time, however, the running rails must be mutually electrically isolated for the maintenance of a signal voltage therebetween, the disappearance of which is due to the axles of a train shunting the rails, signals the presence of the train in a given section of track, in well-known manner. To avoid confusion of the signal voltage with d.c. voltages due to traction, the signal voltage employed is a.c. of several tens, hundreds, or even thousands of hertz. Thus the necessity arises of providing a connection between the rails which has a relatively very low resistance to d.c. while presenting a relatively high impedance to the a.c. signal voltage. To meet such requirements, an arrangement known as an impedance bond has been devised. This takes the form of a relatively high current centre-tapped d.c. winding the two halves of which are inductively coupled in opposite senses (for currents flowing in one direction from the centre tap outwards) to a relatively low

current a.c. winding serving as an a.c. signal receiving or transmitting winding. The ends of the d.c. winding remote from the centre tap are connected each to a respective rail to provide low d.c. resistance paths from the rails to the centre tap, while the a.c. voltage between the rails experiences a relatively high impedance due to the inductance of the a.c. winding. An impedance bond is connected to the rails adjacent to and on one side of a respective electrically insulating fish-plate in each rail (to divide the track into a.c. isolated sections for known signalling purposes), and a further impedance bond is connected between the rails on the other side of the insulating joints, the centre taps of each bond being connected together to provide d.c. continuity between the a.c. isolated sections of track. A.C. signal transmission and/or reception for signalling purposes for each adjacent section is provided by the respective a.c. winding of the respective bonds. Additionally, adjacent tracks may be d.c. coupled to spread the number of paths for traction return current between four or more rails. The centre taps of bonds on adjacent tracks are connected together, the a.c. winding of each bond having a respective capacitor of suitable capacitance connected thereto to form a series-resonant circuit and hence a high a.c. impedance (thus substantially mutually a.c. isolating the d.c. coupled rails and preventing a false a.c. signal voltage shunt that would interfere with the train signalling function). Other rail coupling arrangements utilising impedance bonds are also known.

Such impedance bonds have been known and used for many years. However they suffer at least one practical disadvantage, as now described. Because of the very high direct currents, the connections between the bond and the rails require to be as short as possible to reduce resistance losses, and also since magnetic unbalance between the two halves of the d.c. windings would give rise to spurious and undesired a.c. signals under non-steady state d.c. conditions, e.g. as could occur if the rails currents differed by about 10%, the connections between the bond and

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the rails should, as well as being as short as possible, be as equal in length as possible. These requirements dictate that an impedance bond should be centrally located between the rails to which it is connected. However, prior art impedance bonds are bulky electromagnetic structures and are commonly enclosed in a tank full of dielectric oil for electrical insulating and cooling purposes, giving rise to a structure of substantial dimensions. On the other hand, clearances must be provided for the passage of trains, and so impedance bonds are customarily at least partially buried in an inter-rail recess or pit. The present invention proposes a solution to the problem of having to bury impedance bonds, by providing an impedance bond having a low profile enabling it to be mounted on top of the rail sleepers and yet provide the mandatory clearances for the passage of rail vehicles.

According to the present invention there is provided an impedance bond for electrically connecting adjacent railway track sections of an electrified railway in which the running rails carry return traction current comprising a generally planar concentric winding structure of elongate loop configuration consisting of a high-current d.c. winding having terminals for connection to respective running rails of a track section and a centre tapping for connection to a corresponding centre tapping of an impedance bond in an adjacent section, and a low current a.c. winding to provide through inductive coupling with the d.c. winding means for connecting an a.c. signal to the track rails, and magnetic circuit means embracing the long arms of the elongate winding loops, the arrangement being such that the structure may be mounted horizontally between the running rails and above the track bed and its height is sufficiently low to provide substantial under-vehicle clearance.

Said d.c. winding and said a.c. winding are preferably inductively linked by one or a plurality of loops of ferro-magnetic material encompassing each winding, the or each said loop preferably being laminated in a sense to substantially obstruct the passage of eddy currents parallel to the directions or currents in said windings, and the or each said loop preferably having at least one loop-interrupting gap containing a magnetically unsaturable material (for example air or a plastics material) whereby to prevent saturation of said ferro-magnetic material in use, said gap preferably having a thickness which is small relative to the mean flux path distance round the loop. The loops may be "C"-cores whereby the impedance bond may be assembled by placing such cores onto said windings in pairs from opposite directions whereby each pair forms a said loop, and where a saturation-prevent-

ing gap is to be included in a loop, there may be a sheet of plastics material or other suitable magnetically unsaturable electrically insulating material interposed between the cores of a pair of C-cores forming a loop.

The d.c. winding may be a number of substantially rectangular loops and may have four turns preferably arranged in two-by-two configuration in cross-section, that is to say, in the plane of the winding there are two concentric loops and in a direction at right angles to said plane, there are two layers of two concentric loops. The a.c. winding may be a rectangular loop, preferably wound on a plastics former, and may nestle inside the rectangular loop of the d.c. winding, preferably without extending above or below the vertical upper and lower limits of the d.c. winding. The a.c. winding may have forty five times as many turns as the d.c. winding, and may have one hundred and eighty turns. The d.c. winding may be formed of rectangular or square cross-section straight bars welded or brazed or soldered or bolted or rivetted together at the ends thereof to form said rectangular loops. The specific resistance the cross-sectional area, and the length of the d.c. winding are preferably such that the resistance of the d.c. winding between the end terminals thereof does not exceed one milli-ohm, and may be one fifth of one milli-ohm. The impedance of said a.c. winding is preferably at least 1.8 ohms at 1.5 volts and fifty hertz, and at least 2.4 ohms at 1.5 volts and seventy-five hertz. There may be a further a.c. winding also inductively coupled with said d.c. winding, said further winding being an A.T.P. (automatic train protection) signal transmitter and/or receiver coil. Said further a.c. winding may have four turns.

In order that the invention may be more clearly understood and readily put into effect, a preferred embodiment of the same will now be described with reference to the accompanying drawings wherein:—

Fig. 1 is a part-sectioned perspective view of a prior art impedance bond;

Fig. 2 is a part-section plane view of the preferred embodiment;

Fig. 3 is a transverse cross-section of the preferred embodiment on the line III—III in Fig. 2;

Fig. 4 is an end view of the preferred embodiment;

Fig. 5 is a side view of the preferred embodiment;

Fig. 6 is a highly schematic perspective diagram of the d.c. winding, on its own, of the preferred embodiment; and

Fig. 7 is a perspective view of a slightly modified version of the preferred embodiment.

Referring first to Fig. 1, this shows a

prior art impedance bond (in fact, the Westinghouse "Style P3" impedance bond). In general terms it comprises a deep cast iron box 10 with a bolted-on lid 12. Situated within the box 10 is a laminated double-window "E" core 13 of transformer steel, capped by a similarly laminated bar or block 16 of the same ferro-magnetic material to complete the double-loop magnetic flux-path circuit, a thin layer of magnetically unsaturable material 18 being interposed between the core 14 and the bar or block 16 to form magnetically unsaturable "air" gaps. A heavy current d.c. winding is formed in two halves 20 and 22 from loops of substantial rectangular cross-section copper bar wound round the centre limb of the E core 14, the two halves 20 and 22 being electrically joined in series by a copper bar 24 forming a centre tap of the d.c. winding, the bar 24 having holes 26 for bolted-on connections (not shown) e.g. to the centre-tap of another such impedance bond (not shown). Of the ends of the d.c. winding electrically remote from the centre-tap 24, only the end terminal 28 is visible, this end terminal 28 and the other end terminal (hidden behind the far corner of the lid 12) being for connection to respective running rails (not shown) of a duo-rail railway system powered by direct current and utilising both running rails for carrying traction return current in known manner.

Also wound round the centre limb of the E core 14, is a multi-turn tape-insulated a.c. winding 30 whose terminals, such as 32, are located within an external a.c. terminal box 34 integral with the box 10. It is highly significant that the winding 30 is placed on top of the windings 20 and 22, in that this means that the limbs of the core 14 must be tall enough to accommodate the height of all three windings, which in turn requires a substantial depth of the box 10 to accept the full vertical extent of the core 14 and the bar or block 16 (the latter does not normally extend above the rim of the box 10, since the box 10 is normally filled with a dielectric oil for insulating and cooling purposes (and to extend the thermal time constant of the impedance bond the better to cope with overload conditions), and all the electric and magnetic parts of the bond are intended to be submerged in the oil).

Thus it will be seen that the d.c. windings 20 and 22 have a height comparable to their lateral dimensions, and that the a.c. winding 30 is placed on the top of the d.c. windings 20 and 22 to add to the height of the bond. Since for reasons previously set out, the impedance bond is located between the running rails and yet the lid 12 must not extend vertically upwards, relative to the running rails, to intrude upon the clearance required beneath railway vehicles travelling along

the running rails, the box 10 must be at least partially buried in the ballast and underlying soil. This disadvantage (i.e. the necessity of burial) of the prior art impedance bonds, of which the bond illustrated in Fig. 1 is a typical example, is overcome by the relatively low vertical height of impedance bonds in accordance with the invention, as will now be described.

Referring now to Figs. 2—5, a preferred embodiment of impedance bond in accordance with the invention comprises a base-plate 40 having secured thereto core-locating cradles 42 within which, lying on their backs, are two rows of lower "C" cores 44 which co-operate with corresponding downwardly facing but otherwise identical upper "C" cores 46 to form magnetic loops, as is most clearly seen from Fig. 3. The cores 44 and 46 may conveniently be formed by winding an elongated strip of transformer steel (or other suitable magnetic material) into generally rectangular toroids, and then slitting the so-formed toroids into two "C" cores by lateral cuts. The toroidal winding of the strip means that such cores are made with a suitably laminated form to substantially eliminate eddy currents therein, in use.

Assuming for the moment that the upper cores 46 are not present, then in the two troughs formed by the two rows of lower cores 44 are laid a concentric arrangement of a heavy-current d.c. winding 48 and a former loop 50 containing a low-current a.c. winding 52 (see Fig. 3). The d.c. winding 48 is formed of eight rectangular cross-section longitudinal bars 54, 56, 58, 60, 62, 64, 66 and 68 (see Fig. 3), the sequence of their referencing indicating their order from a first d.c. terminal 70 on an extended end of the bar 54 to a second d.c. terminal 72 on an extended end of the bar 68, as will subsequently be explained with reference to Fig. 6. The eight bars 54—68 are the portions of the d.c. winding 48 which are inductively linked, by the cores 44 and 46, to the a.c. winding 52, but not all portions of the d.c. winding 48 are so linked, and further rectangular cross-section bars 74, 76, 78, 80, 82, 84 and 86 transversely link, in series, the bars 54—68 to form a conductively complete winding (48). It will be noted, from Fig. 3 especially, that the bars 54—68 are in two-by-two rectangular configuration, that is to say, the bar 62 and 66 are side-by-side in a lower layer directly under the upper layer of the two side-by-side bars 54 and 58, and similarly the bars 64 and 68 are side-by-side in a lower layer directly under the upper layer of the two side-by-side bars 56 and 60. Layers 69 of electrically insulating material mutually isolate the bars 54—68. In Fig. 6, in which only the bars 54—68 and 74—86 are shown for clarity, imaginary diamonds 130

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88 and 90 have been drawn to link the bars 54—68, the diamonds 88 and 90 representing rectangles viewed in perspective and being intended to make clearer the layered two-by-two rectilinear configuration described above. It will clearly be seen from Fig. 6 how the winding 48 progresses between the d.c. end terminals 70 and 72. Starting at the d.c. end terminal 70, which is on the extended end of the bar 54, the winding 48 proceeds as follows from the terminal 70 by way of the longitudinal bar 54, transverse bar 74, longitudinal bar 56, transverse connecting bar 76, which is in the same upper plane as the bars 54, 56, 58 and 60, bar 58 which is above the bar 66, the transverse connecting bar 78, 78, stepped above the plane of the bars 54, 56, 58 and 60 by slightly more than the uniform height of the bars 54—68 and longitudinal bar 60. Next cranked connecting bar 80 which joins longitudinal bars 60 and 62, is provided with a centre tapping 92. The remainder of the winding comprises bar 62, the stepped transverse connecting bar 82, longitudinal bar 64, transverse connecting bar 84 in the same lower plane as the bars 62, 64, 66 and 68, longitudinal bar 66, transverse connecting bar 86 and bar 68 which is extended outwardly to the second d.c. terminal 72. Except for the transverse connecting bars 78 and 82, all the bars lie in one or other (and the transverse connecting bar 80 in both) of the upper and lower planes referred to above, and the vertical upward and downward excursions of the bars 78 and 82 do not exceed the vertical limits of the cores 44 and 46 when they are in place, as may clearly be seen from Fig. 4. This together with the placing of the a.c. winding 52 concentrically within the bars 54—68, the former 50 not extending vertically above or below the bars 54—68, results in a winding structure which is generally planar, and has vertical dimensions, i.e. dimensions at right angles to the general plane of the windings 48 and 52, which are small relative to the length and breadth of the generally rectilinear windings 48 and 52 in said general plane, and which are also minimal in absolute terms. (It will be noted that to enhance the low vertical dimension of the structure, the bars 54—68 and also the transverse connecting bars 74—86, are laid so that the lesser dimension of their rectangular cross-sections is vertical, i.e. their greater cross-sectional dimension is horizontal; see Fig. 3).

Assuming the windings 48 and 52 to have been placed within the troughs formed by the cores 44, the magnetic structure of the impedance bond is completed by laying on the ends of the cores 44, strips 45 of thin plastics sheeting (e.g. of polyethylene or polypropylene) or thin strips 45 of resin-impregnated fabric (e.g. of "Tufnol", (Trade

Mark)) in order to create magnetically unsaturable gaps in the magnetic loops encircling the windings 48 and 52, and by finally placing the upper C cores 46 on top of corresponding lower C cores 44 to form respective closed magnetic loops. Clamping means (not shown; for example tensioned metal banding) are placed round conjugate pairs of the cores 44 and 46 to secure the structure together.

The horizontal slitting of the loops formed by aligned pairs of the cores 44 and 46 enables a simple assembly procedure for the impedance bond. Firstly, the base plate 40 with its cradle 42 are laid down, secondly the cores 44 are dropped into the cradle 42, thirdly the d.c. winding 48 is placed on the cores 44, fourthly the former 50 with its winding 52 is placed on the cores 44 within the winding 48, fifthly the unsaturable strips 45 are laid in position on top of the ends of the cores 44, and sixthly the cores 46 are placed on top of the windings 48 and 52 in alignment with respective ones of the cores 44. The cores 44 and 46 are then ready for banding or any other suitable securing method, and the bond then needs only the electrical connection of the terminals of the winding 52 to a terminal block 95 in an enclosed terminal box 96, and the securing of a protective cover (to be described later).

The toroids forming the magnetic loops constituted by the cores 44 and 46 in pairs could be slit in a vertical plane for sideways placement of the cores on the windings 48 and 52, but the horizontal slitting shown in the drawings is preferred for ease of assembly.

The bars 54—68 and the bars 74—86 are electrically connected together at their respective junctions in any suitable manner providing very low resistance joints. Preferably bar jointing is performed by brazing the bars together, but alternatively they could be welded, soldered, bolted, or riveted.

Leads 94 from the a.c. winding 52 are taken out to an a.c. terminal box 96 secured on the baseplate 40 (see Figs. 2 and 5).

A further a.c. winding (not shown) may be wound concentric with the winding 52, and also terminated in the box 96, the further a.c. winding being for the transmission or reception of A.T.P. signals.

As may be seen from Figs. 3, 4 and 5, the above described electro-magnetic structure is provided with a rain shield in the form of a sheet cover 98, bevelled downwards at the edges, which as may be seen most clearly from Fig. 3, adds negligibly to the height of the impedance bond. It will also be clearly seen from Figs. 3, 4 and 5 how the impedance bond is open to the atmosphere around its periphery. Thereby the bond is air-cooled; by convection and radiation in still-air weather conditions and more forcefully by breezes and winds and the draught of

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passing railway vehicles. The use of air-cooling eliminates the requirements of the expense and bulk of an oil-tight container, the expense of the oil itself, and the necessity of taking precautions against oil-leakage. (While it is preferred that an impedance bond in accordance with the invention is air-cooled, such a bond may, if desired or necessary, be oil-cooled, only a relatively shallow oil tank being required).

The low vertical height of the above described impedance bond in accordance with the invention means that such a bond can be mounted between the running rails entirely on top of conventional sleepers, without the necessity of providing a recess or pit to accommodate the bond, and yet provide the necessary under-vehicle clearance.

The above described impedance bond in accordance with the invention functions electrically and magnetically in identical fashion to known prior art impedance bonds, and so the functioning of the preferred embodiment need not be detailed here.

Fig. 7 illustrates in perspective view a slightly modified form of impedance bond in accordance with the invention (without the rain-protection cover). Parts of the Fig. 7 embodiment which directly corresponds to the embodiment of Figs. 2-6 are given the same reference numerals, the electric and magnetic structures of the two embodiments being substantially identical.

The basic difference between the two embodiments lies in the external mechanical details. In place of the base plate 40, there is provided an angle-iron framework 100 in the form of rectangular assemblies at the front and back of the bond, which support the d.c. winding 48 (of which parts 54, 56, 58, 60, 62, 70, 72, 74, 76, 78 and 80 are referenced in the drawing) through the intermediary of sheets 102 of electrically insulating material, as well as the layers of insulating material 69. The d.c. winding 48, being formed of substantial cross-section bars and therefore being rigid, readily supports the weights of the cores 44 and 46 (the means securing together conjugate pairs of cores 44 and 46 being omitted from Fig. 7). Each end assembly 100 would, in use, be screwed or bolted down to a respective sleeper. Means, e.g. tie-bolts, holding together the end assemblies 100 are omitted for the sake of clarity.

Other modifications and variations may be made within the scope of the invention. For example, other forms of magnetic circuit may be employed, and different numbers of "turns", from one upwards, may be employed in the d.c. winding.

Whilst in the foregoing the heavy current winding has been referred to more specifically as a d.c. winding, it will be appreciated that

such an impedance bond according to the invention could equally well be employed in a.c. rail territories. It will be appreciated however that, owing to the higher voltage and lower level of traction currents usual in a.c. territories, impedance bonds are less frequently a requirement.

WHAT WE CLAIM IS:—

1. An impedance bond for electrically connecting adjacent railway track sections of an electrified railway in which the running rails carry return traction current comprising a generally planar concentric winding structure of elongate loop configuration consisting of a high current d.c. winding having terminals for connection to respective running rails of a track section and a centre tapping for connection to a corresponding centre tapping of an impedance bond in an adjacent section, and a low current a.c. winding to provide through inductive coupling with the d.c. winding means for connecting an a.c. signal to the track rails, and magnetic circuit means embracing the long arms of the elongate winding loops, the arrangement being such that the structure may be mounted horizontally between the running rails and above the track bed and its height is sufficiently low to provide substantial under-vehicle clearance.

2. An impedance bond as claimed in Claim 1 wherein the high current d.c. winding means comprises a plurality of conductive bars connected to form a continuous winding having a plurality of turns arranged to pass through the magnetic circuit means.

3. An impedance bond as claimed in Claim 2, wherein the a.c. winding means comprises a plurality of turns made up on a former located inside the inner circumference of the high current d.c. winding.

4. An impedance bond as claimed in any preceding claim wherein the magnetic circuit means includes a plurality of rows of loops covers each of which comprises co-operating "C" cores between the abutting faces of which are inserted strips of magnetically unsaturable material whereby to form magnetically unsaturable gaps.

5. An impedance bond as claimed in Claim 4 wherein the co-operating part of the "C" cores comprises upper and lower halves and the lower halves are located by core-supporting means whereby the magnetically unsaturable gaps lie in a horizontal plane.

6. An impedance bond as claimed in Claim 5 wherein the core-supporting means comprises d.c. winding means sufficiently rigid to support the loop-core means and in turn insularly supported by means of a frame adapted to be secured to the track bed.

7. An impedance bond as claimed in any preceding claim wherein the magnetic



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passing railway vehicles. The use of air-cooling eliminates the requirements of the expense and bulk of an oil-tight container, the expense of the oil itself, and the necessity of taking precautions against oil-leakage. (While it is preferred that an impedance bond in accordance with the invention is air-cooled, such a bond may, if desired or necessary, be oil-cooled, only a relatively shallow oil tank being required).

The low vertical height of the above described impedance bond in accordance with the invention means that such a bond can be mounted between the running rails entirely on top of conventional sleepers, without the necessity of providing a recess or pit to accommodate the bond, and yet provide the necessary under-vehicle clearance.

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2. An impedance bond as claimed in Claim 1 wherein the high current d.c. winding means comprises a plurality of conductive bars connected to form a continuous winding having a plurality of turns arranged to pass through the magnetic circuit means.

3. An impedance bond as claimed in Claim 2, wherein the a.c. winding means comprises a plurality of turns made up on a former located inside the inner circumference of the high current d.c. winding.

4. An impedance bond as claimed in any preceding claim wherein the magnetic circuit means includes a plurality of rows of loops covers each of which comprises co-operating "C" cores between the abutting faces of which are inserted strips of magnetically unsaturable material whereby to form magnetically unsaturable gaps.

5. An impedance bond as claimed in Claim 4 wherein the co-operating part of the "C" cores comprises upper and lower halves and the lower halves are located by core-supporting means whereby the magnetically unsaturable gaps lie in a horizontal plane.

6. An impedance bond as claimed in Claim 5 wherein the core-supporting means comprises d.c. winding means sufficiently rigid to support the loop-core means and in turn insularly supported by means of a frame adapted to be secured to the track bed.

7. An impedance bond as claimed in any preceding claim wherein the magnetic

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loop-core means has a laminated construction.

5 8. An impedance bond as claimed in any preceding claim provided with an open-sided protective covering whereby to permit air-cooling of the winding.

9. An impedance bond substantially as

described herein with reference to Figs. 2 to 6 of the accompanying drawings.

10. An impedance bond substantially as described herein with reference to Fig. 7 of the accompanying drawings.

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