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SPECIFICATION **Improvements in or relating to multi-frequency** **control arrangements**

This invention relates to multi-frequency control arrangements and particularly to speed limit control arrangements in automatic train protection systems.

- In one type of automatic train protection system, a speed limit imposed on a section of track is indicated to a train in that section by means of a modulated or coded carrier signal transmitted to the train. The speed limits are fixed at convenient speed intervals, up to the permitted maximum speed, and each is represented by a different modulation or coding frequency. One of the first operational systems of this type is described in U.K. Patent No. 980,687 and was installed on London Transport's Victoria Line. Another similar system has also been installed on the Spanish Madrid Underground Line No. 7. Normally a carrier signal is fed into one of the running rails and the other is used as a signal return path so that a conductive loop is formed from a signal transmitter only when a train is in the section. Pick-up coils mounted ahead of the train's front axle sense the resulting currents flowing through the rails when the loop is completed. The received signals are fed from the pick-up coils to the inputs of a number of parallel filter detector channels, one for each speed limit code frequency, and the speed limit is interpreted according to which detector channel is energised. Alternatively, an insulated wire loop may be laid on the track bed between or alongside the rails to provide an inductive coupling link with the train's pick-up coils.

- The safety of a train is of paramount importance and any train controlling and/or signalling system must be designed such that any failure causes the system to occupy a safe state. For example, in the Victoria Line Underground, mentioned above, the train's frequency detector channels include straightforward L—C filters to determine the centre frequency and bandwidth of each channel. The value of both inductors and capacitors can only decrease, so the centre frequency of an L—C filter can only increase in value. Therefore, on the Victoria Line, progressively higher code frequencies correspond to progressively higher speed limits, so that in the event of a filter characteristic becoming degraded, it responds to a higher frequency but interprets it as a lower speed limit. The safety of a train is thus preserved in the event of such a fault occurring. Another example of the same fail-safe action occurs in respect of harmonic generation and erroneous detection. For example, in certain circumstances, harmonics of a fundamental coding frequency can be generated. Thus, the second harmonic of a coding frequency representing a low speed could lie within a higher speed channel frequency bandwidth unless the coding frequencies are carefully chosen to prevent such an occurrence. The code frequency

- transmitters have a known tolerance about their design frequencies which, combined with the centre frequency tolerances of the receiver channel filters, produces minimum filter bandwidths. Considering the allocation of code frequencies as a whole, it is readily appreciated that to space the frequencies to obviate problems from harmonic generation, to avoid bandwidth overlapping, and to take account of other attendant difficulties and restraints such as traction supply frequency, track-bed leakage and the electrical characteristics due to using the running rails as a transmission line, the number of possible frequencies are severely restricted. In fact, the Victoria Line used only four such frequencies which adequately fulfilled the required control functions. However, on other railways where trains are to be permitted to reach higher speeds, for example, it is necessary to accommodate more code frequencies in the available frequency spectrum without impairing or compromising vital safety standards.

An object of the present invention is to provide an arrangement of code frequencies permitting the transmission of a maximum number of speed limits whilst preserving at least the accepted minimum safety standards.

- According to the present invention there is provided an automatic train protection system in which a selected one of a number of predetermined possible maximum speed limits for a section of track is transmitted by means of a coded signal from a frequency transmitter, and is detected and interpreted by a receiving/detecting means carried by a train in that section, and each possible speed limit is individually represented by a different coding frequency, having an arrangement of coding frequencies comprising a first group of frequencies representing the lowest speed limits lying within a frequency range of one octave, and at least one further coding frequency representing a further and higher speed limit lying at a frequency lower than the said octave of frequencies, so that if a fault condition occurs whereby harmonics of the coding frequencies are detected by the train, then harmonics of the higher speed limit frequencies are interpreted by the train as lower speed limits.

Preferably the lower frequency or frequencies lie within the octave immediately below the octave of the first group of frequencies.

- In order that the invention may be more clearly understood and readily put into effect, an embodiment of a preferred form of the invention will now be described, by way of example, with reference to the accompanying drawing, which shows a two-octave code frequency spectrum of an underground railway automatic train protection system having six speed limits.

In the automatic train protection system including the embodiment of the invention to be described, it was decided to use 2 kilohertz as the carrier frequency. Audio-frequency carrier signals for such applications are typical as the running rails show acceptable transmission line

characteristics at such frequencies, transmitter power is not too high, track bed leakage is acceptable and cross-talk between adjacent tracks is below reasonable threshold limits. The method of modulation chosen in the present example was square-wave pulsing of the carrier signal. For a carrier frequency of 2 kHz square-wave distortion is minimal up to a frequency of approximately 60 Hz, above this frequency pulse leading and trailing edges deteriorate due to harmonic distortion. Thus this system has an effective upper coding frequency limit of 60 Hz. However the railway system concerned is electric traction motors supplied by electric power at 50 Hz and the usable upper coding frequency limit is therefore reduced further.

At the other lower end of the frequency spectrum a practical limit is set by the acceptable size of components, particularly in the receiver filter/detector channels in the train-borne equipment. To the same extent, therefore, the lower frequency limit was set arbitrarily and in this case 10 Hz was chosen.

Thus, the practical coding frequency spectrum extends from approximately 10 Hz to 45 Hz, within which lies two adjacent octaves, for example, 10 to 20 Hz and 20 to 40 Hz.

The carrier signal transmitters have a working tolerance of $\pm 4\%$ on their nominal frequency settings, which is shown diagrammatically in the accompanying drawing. An adequate minimum safety margin between adjacent frequency channels was specified as 3%. It will be apparent from the drawing, and can be shown mathematically, that four is the maximum number of frequency channels which could therefore be accommodated by one octave. In the example being described, these four frequencies were set at 23.31 Hz, 27.58 Hz, 32.63 Hz and 38.60 Hz, and represent speed limits of 15 k.p.h., 40 k.p.h., 65 k.p.h., respectively, that is progressively higher speeds are represented by progressively higher frequencies.

However, the receiving bandwidths need not be so severely restricted and may overlap with their neighbours, providing an adequate margin is retained between a receiver bandwidth limit and an adjacent transmitter bandwidth limit.

In one A.T.P. system, a further and fifth speed limit of 90 k.p.h. was required, a frequency of 14.78 Hz was therefore chosen. The second harmonic of this frequency is 29.56 Hz so that if a 90 k.p.h. speed limit signal is either faultily transmitted as a signal containing the second harmonic or is so received then the signal is detected on the train and interpreted as a signal representing a 40 k.p.h. speed limit. The safety of the train is therefore maintained because it must respond to the lower speed limit signal.

It is normal practice in speed limit setting systems that the receiver in the train is so constructed that, in the event of two or more signals being received simultaneously, the train can only respond to the lowest speed signal, and in the event of no signal being received, the train's

emergency brakes are applied.

In another A.T.P. system, a further and sixth speed limit was required at 100 k.p.h. A further frequency at 10.48 Hz was chosen, but this was used to represent 90 k.p.h. and 14.78 Hz represented 100 k.p.h. Thus, the second harmonics at 21.96 Hz and 29.56 Hz, respectively, represent 15 k.p.h. and 40 k.p.h. In this way, if a fault should occur, a disproportionate penalty is not applied to the train's running speed.

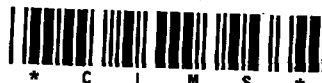
As mentioned above, inductor and capacitor values only decrease in value so that the centre frequency of the train's receiving channel filters only increases. For frequencies f_2 to f_5 in the drawing, this means that if a channel frequency drifts sufficiently to detect the adjacent higher frequency this can only result in a right-side failure. This is also true in respect of frequency f_0 , however, if the f_1 filter increase sufficiently it would respond to a lower speed limit frequency. It is therefore preferred, for safety reasons, to leave a sufficient frequency gap between the highest frequency in the lower octave and the lowest frequency in the higher octave to reduce the chance of such an occurrence to negligible magnitude. This is achieved by leaving a 31% safety margin between the f_1 and f_2 channels, which would require a 70% change in either inductor or capacitor value in a simple inductor-capacitor filter circuit. Furthermore, the threshold levels in the receiver channels are set such that if such a change were to take place that the Q value of the filter would have reduced below the level required to produce a channel response. In which case, the train's emergency brakes would not be released or the train would only recognise a 15 k.p.h. speed limit.

CLAIMS:

1. An automatic train protection system in which a selected one of a number of predetermined possible maximum speed limits for a section of track is transmitted by means of a coded signal from a frequency transmitter, and is detected and interpreted by a receiving/detecting means carried by a train in that section, and each possible speed limit is individually represented by a different coding frequency, having an arrangement of coding frequencies comprising a first group of frequencies representing the lowest speed limits lying within a frequency range of one octave, and at least one further coding frequency representing a further and higher speed limit lying at a frequency lower than the said octave of frequencies, so that if a fault condition occurs whereby harmonics of the coding frequencies are detected by the train, then harmonics of the highest speed limit frequencies are interpreted by the train as lower speed limits.

2. An automatic train protection system according to Claim 1, wherein the first group of frequencies lies within a first octave and further coding frequencies lie within a second octave comprising frequencies lower than that of the first.

3. An automatic train protection system



characteristics at such frequencies, transmitter power is not too high, track bed leakage is acceptable and cross-talk between adjacent tracks is below reasonable threshold limits. The

method of modulation chosen in the present example was square-wave pulsing of the carrier signal. For a carrier frequency of 2 kHz square-wave distortion is minimal up to a frequency of approximately 60 Hz, above this frequency pulse leading and trailing edges deteriorate due to harmonic distortion. Thus this system has an effective upper coding frequency limit of 60 Hz. However the railway system concerned is electric traction motors supplied by electric power at 50 Hz and the usable upper coding frequency limit is therefore reduced further.

At the other lower end of the frequency spectrum a practical limit is set by the acceptable size of components, particularly in the receiver filter/detector channels in the train-borne equipment. To the same extent, therefore, the lower frequency limit was set arbitrarily and in this case 10 Hz was chosen.

Thus, the practical coding frequency spectrum extends from approximately 10 Hz to 45 Hz, within which lies two adjacent octaves, for example, 10 to 20 Hz and 20 to 40 Hz.

The carrier signal transmitters have a working tolerance of $\pm 4\%$ on their nominal frequency settings, which is shown diagrammatically in the accompanying drawing. An adequate minimum safety margin between adjacent frequency channels was specified as 3%. It will be apparent from the drawing, and can be shown mathematically, that four is the maximum number of frequency channels which could therefore be accommodated by one octave. In the example being described, these four frequencies were set at 23.31 Hz, 27.58 Hz, 32.63 Hz and 38.60 Hz, and represent speed limits of 15 k.p.h., 40 k.p.h., 65 k.p.h., respectively, that is progressively higher speeds are represented by progressively higher frequencies.

However, the receiving bandwidths need not be so severely restricted and may overlap with their neighbours, providing an adequate margin is retained between a receiver bandwidth limit and an adjacent transmitter bandwidth limit.

In one A.T.P. system, a further and fifth speed limit of 90 k.p.h. was required, a frequency of 14.78 Hz was therefore chosen. The second harmonic of this frequency is 29.56 Hz so that if a 90 k.p.h. speed limit signal is either faultily transmitted as a signal containing the second harmonic or is so received then the signal is detected on the train and interpreted as a signal representing a 40 k.p.h. speed limit. The safety of the train is therefore maintained because it must respond to the lower speed limit signal.

It is normal practice in speed limit setting systems that the receiver in the train is so constructed that, in the event of two or more signals being received simultaneously, the train can only respond to the lowest speed signal, and in the event of no signal being received, the train's

emergency brakes are applied.

In another A.T.P. system, a further and sixth speed limit was required at 100 k.p.h. A further frequency at 10.48 Hz was chosen, but this was used to represent 90 k.p.h. and 14.78 Hz represented 100 k.p.h. Thus, the second harmonics at 21.96 Hz and 29.56 Hz, respectively, represent 15 k.p.h. and 40 k.p.h. In this way, if a fault should occur, a disproportionate penalty is not applied to the train's running speed.

As mentioned above, inductor and capacitor values only decrease in value so that the centre frequency of the train's receiving channel filters only increases. For frequencies f_2 to f_6 in the drawing, this means that if a channel frequency drifts sufficiently to detect the adjacent higher frequency this can only result in a right-side failure. This is also true in respect of frequency f_0 , however, if the f_1 filter increase sufficiently it would respond to a lower speed limit frequency. It is therefore preferred, for safety reasons, to leave a sufficient frequency gap between the highest frequency in the lower octave and the lowest frequency in the higher octave to reduce the chance of such an occurrence to negligible magnitude. This is achieved by leaving a 31% safety margin between the f_1 and f_2 channels, which would require a 70% change in either inductor or capacitor value in a simple inductor-capacitor filter circuit. Furthermore, the threshold levels in the receiver channels are set such that if such a change were to take place that the Q value of the filter would have reduced below the level required to produce a channel response. In which case, the train's emergency brakes would not be released or the train would only recognise a 15 k.p.h. speed limit.

CLAIMS

1. An automatic train protection system in which a selected one of a number of predetermined possible maximum speed limits for a section of track is transmitted by means of a coded signal from a frequency transmitter, and is detected and interpreted by a receiving/detecting means carried by a train in that section, and each possible speed limit is individually represented by a different coding frequency, having an arrangement of coding frequencies comprising a first group of frequencies representing the lowest speed limits lying within a frequency range of one octave, and at least one further coding frequency representing a further and higher speed limit lying at a frequency lower than the said octave of frequencies, so that if a fault condition occurs whereby harmonics of the coding frequencies are detected by the train, then harmonics of the highest speed limit frequencies are interpreted by the train as lower speed limits.

2. An automatic train protection system according to Claim 1, wherein the first group of frequencies lies within a first octave and further coding frequencies lie within a second octave comprising frequencies lower than that of the first.

3. An automatic train protection system



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according to Claim 2, wherein the second octave lies immediately below the first octave.

4. An automatic train protection system according to any preceding claim including transmitting means having known bandwidths for transmitting at each coding frequency, and the arrangement of coding frequencies is such that the transmitting bandwidths are in non-overlapping relationship.

5. An automatic train protection system according to Claim 4, wherein the bandwidths of the receiving/detecting means are in overlapping relationship with each other but do not overlap adjacent frequency transmitter bandwidths.

6. An automatic train protection system according to any preceding claim, wherein there are four coding frequencies in the first octave.

7. An automatic train protection system

20 according to any preceding claim, wherein progressively higher frequencies lying within the first or further octave represent progressively higher speeds.

8. An automatic train protection system according to any preceding claim, wherein the receiving/detecting means comprises a plurality of channels, each responsive to an individual coding frequency and having a frequency sensitive response characteristic, and the highest of the further coding frequencies is spaced sufficiently from the lowest coding frequency in the first octave such that a receiving/detecting channel for the latter frequency is not responsive to the further lower coding frequency.

9. An automatic train protection system, substantially as described herein, with reference to the accompanying drawings.