**Title:** OBJECT DETECTION AND ANALYSIS WITH TRANSMISSION LINES

**Abstract**

A method of detecting or analysing an object or other discontinuity in a medium in the vicinity of a transmission line (1), the discontinuity being such as to cause reflection of a signal transmitted along the transmission line. The method comprises the steps of: (a) transmitting a signal along the transmission line; (b) monitoring the transmission line for any reflections of the signal; (c) generating an analysis window of time $t_1$, $t_2$, $t_3$ if the magnitude of a given characteristic of the reflected signal is greater than a predetermined threshold value; and (d) analysing the reflected signal received during the period of an analysis window to provide the required information on the discontinuity.

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OBJECT DETECTION AND ANALYSIS WITH TRANSMISSION LINES

Field of the Invention

The invention relates to transmission lines and more specifically to a method of detecting or analysing an object or other discontinuity in the vicinity of a transmission line.

Background to the Invention

It is known to use a transmission line to determine the level of an interface between fluids in a container. A pulsed electrical signal is applied to the transmission line, which is immersed in the fluids. The electrical signal is reflected as a result of the change of impedance of the line caused by the interface. Given the velocity of propagation of the transmitted signal along the transmission line, the position of the interface can be ascertained from the delay between the application of the transmitted signal and the reception of the reflected signal. Such a technique is known as Time Domain Reflectometry (TDR).

United States Patent No 4 450 434 (Nielsen et al) and UK Patent No 1 351 654 (McFerrin) show that it is also known to use TDR to locate a break in, or a damaged portion of, a transmission line. In addition US Patent No 4 394 640 (Ross) proposes that TDR be used to detect the position of solid objects, such as vehicles, travelling alongside a transmission line.
Known TDR techniques rarely yield any more information than the location of a change of impedance of a transmission line. It is an object of the present invention to provide a technique which can be used to locate a change in impedance, and which provides the basis for obtaining further information on the source of the change in impedance.

Summary of the Invention

According to the invention there is provided a method of detecting or analysing an object or other discontinuity in a medium in the vicinity of a transmission line, the discontinuity being such as to cause reflection of a signal transmitted along the transmission line, the method comprising the steps of:

a) transmitting a signal along the transmission line;

b) monitoring the transmission line for any reflections of the signal;

c) generating an analysis window of time if the magnitude of a given characteristic of the reflected signal is greater than a predetermined threshold value; and

d) analysing the reflected signal received during the period of an analysis window to provide the required information on the discontinuity.

Preferably the duration of the analysis window corresponds
to the length of time during which the magnitude of said characteristic is greater than said threshold.

The given characteristic may, for example, be the amplitude of the reflected signal, but is preferably the differential of the reflected signal with respect to time.

The required information may be an indication of the position along the transmission line of the discontinuity, in which case the analysis of the reflected signal comprises determining a reception time at which a given point on the reflected signal is received, said indication being obtained from a calculation of the time delay between a start time, when the transmitted signal is applied to the transmission line, and said reception time.

Where said part of the reflected signal corresponding to the discontinuity gives rise to only one analysis window, the given point on the reflected signal is conveniently determined by differentiating the latter with respect to time and ascertaining the time at which the differential is at a pre-determined value.

Where the reflected signal gives rise to more than one analysis window the point on the reflected signal is preferably determined by taking the second differential with respect to time of the reflected signal, and finding an average of the respective times in the analysis windows when the second derivative is at a predetermined value by an appropriate process.

The pre-determined value of the second derivative may be
zero.

If more than one analysis window is created by the reflected signal, an indication of the extent of the discontinuity is obtained by ascertaining the spread of times at which the second differential is at a predetermined value, in the respective analysis windows.

An initial reflected signal may be created as a result of the transmitted signal being reflected at the junction between the transmission line and a cable feeding the transmitted line, and this reflected signal may give rise to an analysis window. In such a case the start time is preferably determined by differentiating the initial reflected signal with respect to time, and ascertaining the time at which the second differential is at a predetermined value.

**Brief Description of the Drawings**

The invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a side view of a transmission line for use in a method according to the invention, and a discontinuity in the form of a solid object;

Figure 2 is a sectional view taken along the line II-II of Figure 1;

Figure 3 is a block circuit diagram of apparatus for generating signals to be applied to the transmission line;
Figure 4 is a graph of the signals applied by the apparatus shown in Figure 3;

Figure 5 is a block circuit diagram of apparatus for receiving and processing reflected pulses which have been transmitted by the apparatus shown in Figure 3; and

Figures 6(a)-(e) show diagrammatically, the analysis of the signals received by the apparatus shown in Figure 5.

Detailed Description

Referring to Figure 1 a transmission line 1 is used to detect or analyse an electrical discontinuity caused by the proximity of an object 2 to obtain information on the latter.

The transmission line 1 comprises an elongate conducting element 3 separated from a ground plane 4 by a dielectric spacer 5. The transmission line is terminated at one end by a resistor R which is connected between the conductor 3 and the ground plane 4, and which has a resistance substantially matching the impedance of the transmission line 1.

An input or feed cable 6 is connected to the conductor 3 at the other end of the transmission line 1, and is also connected to signal input apparatus shown in Figure 3. In the signal input apparatus, an oscillator 7 is connected via a delay generator 8 to a sampler 9. The delay generator 8 is also connected to a pulse step generator 10 which is connected in parallel to the sampler 9. Both the sampler 9 and the generator 10 are connected to the
cable 6.

In use the oscillator 7 feeds a square wave signal having a frequency of 1MHz into the delay generator 8 where the signal is split into two components. The first component is also a 1MHz square wave signal which is relayed to the pulse step generator 10 which is triggered by that component to generate a succession of pulses at a frequency of 1MHz.

The pulse signals produced by the generator 10 are shown in Figure 4. Each input pulse comprises an initial step 11 having a duration of approximately 50ps, a plateau 12 of around 1-4ns and a gradual decay 13. The duration of the plateau 12 corresponds to the length of the transmission line 1 so that, when a pulse is applied to the transmission line 1 at input 6, the portion of the plateau adjacent the step 11 will have reached the end of the transmission line, by the time the pulse begins to decay at the input 6.

The other component of the original 1MHz signal is processed by the delay generator 8 to give a signal having a frequency of slightly less than 1MHz, for example 0.9999MHz. This reduced frequency signal is relayed to the sampler 9, which is consequently triggered to sample the input 6 for any reflected signals returning along the transmission line 1, at the same frequency of the reduced frequency component.

In Figure 5, the oscillator 7, delay generator 8 and pulse step generator 10 are indicated by the box referenced 14 connected to the sampler 9. Pulses generated by the pulse step generator 10 are relayed
directly to the input 6 through the sampler 9, the output of which is connected to signal processing circuitry 15, which comprises a first differentiator 16, a second differentiator 17 and comparator circuitry 18 connected in series. Further comparator circuitry 19 is connected between the output of the differentiator 16 and the comparator circuitry 18, in parallel with the differentiator 17.

Figure 6(a) represents the reflection produced by a single pulse applied to the input 6. When a pulse is applied to the transmission line, there will be an initial reflection, caused by the change in impedance, at the junction between the input cable 6 and the line 1, giving rise to an initial step 20. The object 2 is the source of a discontinuity in the medium surrounding the line 1. and this discontinuity leads to further changes in the impedance of the line in the vicinity of the object 2. Thus, as the pulse travels towards and past the object 2, further reflections of the signal will occur, giving rise to the trough 21 in the reflected signal. The time delay between the step 20 and the trough 21 is indicative of the position along the line of the object 2, whilst the duration (ie width) of the trough is related to the physical extent of the object along the line.

In use the sampler 9 samples a portion of each of a succession of reflected pulses, each pulse being sampled at a slightly later time from its respective initial step than the previous pulse, since the sampler 9 is triggered at a frequency slightly less than 1MHz. Each sample will represent a given position on the line from which a reflection would occur if present in that sample. Thus the sampler 9 effectively scans the length of the
transmission line 1, and constructs a reflection profile corresponding to the graph shown in Figure 6(a), which is fed to the differentiator 16 which differentiates the signal of Figure 6(a) with respect to the time. Figure 6(b) represents the output of the differentiator 16 which produces a first single polarity pulse 22 corresponding to the step 20 and a second, double polarity pulse 23 corresponding to the trough 21.

The output of the differentiator 16 passes into comparator circuitry 19 and into the second differentiator 17. The comparator circuitry 19 determines whether the magnitude of the signal generated by the differentiator 16 is greater than a positive threshold 24 or less than a negative threshold 25, and if it is, generates an analysis window of time, as shown in Figures 6(c) and 6(d), of a duration which corresponds to the time during which the signal is greater than the threshold 24 or less than the threshold 25. Thus three time windows 26, 27 and 28 are generated over respective times \( t_1 \), \( t_2 \) and \( t_3 \), one for the peak 22, and one for each respective peak of the pulse 23. The output signals generated by the comparator circuitry 19 act as enable signals for the comparator circuitry 18.

The differentiator 17 performs a second differentiation with respect to time of the signal generated by the differentiator 16, producing the signal shown in Figure 6(e). This signal is fed to the comparator circuitry 18, which generates a signal when the second differential is zero, and when an enabling signal is being generated by the comparator circuitry 19. Thus the comparator circuitry 18 determines when the second differential of the original signal is zero within each respective window.
in times $t_1$, $t_2$ and $t_3$, i.e. at times 29, 30 and 31 respectively.

The output of the comparator circuitry 18 is relayed to further processing circuitry (not shown), which calculates the average of the times 30 and 31 and the delay between that average and the time 29 to give an indication of the distance along the transmission line 1 of the object 2.

The further processing circuitry may in addition perform further analysis of the signal produced by the comparator circuitry i.e. for example, the further processing circuitry may evaluate the delay between the time when the second differential of the original signal is zero in the window 26, and that when the second differential is zero in the window 27 to give an indication of the extent of the object 2 in the direction of the transmission line 1.

Alternatively, having ascertained the position of the object 2 along the transmission line 1, the further processing circuitry may so control the sampler as to cause the latter to sample the reflected signal at 1MHz, at the time when the trough 21 is at a minimum (i.e. the average of the times 30 and 31. If the object 2 is then moved perpendicularly towards the transmission line 1 at a known velocity, a plot of the change in amplitude of the trough 21 against time is obtained.

Such a plot for a metallic object will be distinguishable from that obtained from a dielectric object, and it can therefore be determined whether the object is a metallic or a dielectric object.

If the object makes contact with the transmission line 1,
and the dielectric spacer 3 is resiliently flexible, the depth of the trough 21 may be analysed in a similar way to give an indication of the pressure of contact between the object 2 and the line 1 if the object 2 is metallic.

Other information which may be derived includes distance from the transmission line of the object causing the discontinuity, the material content of the object, its shape or extent or its movement or slippage against the transmission line, or its separation from a second object. In these cases known characteristics of the object are used to interpret the signal and deduce unknowns.

Such information may be determined by selecting "range windows" from the composite reflected signal, and subjecting the signals observed in those windows to analysis.

The electrical signal may take the form either of a short pulse or a step, and the exact analysis technique will depend on the choice of signal. If a step wave form is used, such range windows may be defined by determining the time during which either the signal value itself or the first derivative of the signal with respect to range exceeds a given value. For a pulse, the amplitude of the signal itself rather than its derivative is used. In the following sections, a step waveform will be assumed.

During each window, various functions of the signal are generated, and derived characteristics of the signal are measured. The functions include the first and second derivatives with respect to range. The derived characteristics include:
(a) The time at which the first or second derivative passes through a defined value which may be zero or may be determined by previous analysis of signals received in the absence of external objects.

(b) The value of the signal at the time determined in (a) from the first derivative.

(c) The value of the first derivative at the time determined in (a) from the second derivative.

(d) The rate of change with time of the value determined in (b) or (c).

(e) The interval between two times as determined in (a).

(f) The peak value of the reflected signal during the interval defined in (e).

Each time (a) is used to determine the location along the transmission line of an edge or an object.

If its material is unknown, the rate (d) is measured when the transmission line is moved laterally towards the object at a known constant rate. This allows the object to be identified as metallic or non-metallic, and may allow inference of its dielectric constant.

The interval measured in (e), based on times arising from the second derivative in (a), indicates the extent of the object for certain shapes.

If its material is known or constrained, and its extent has been determined as greater than a known minimum, its
proximity may be deduced from the value determined in (f).

Motion of the object along the transmission line can be measured as changes with time of the value determined in (a), and slippage or vibration at a known location can be detected from changes in the value determined as in (b) or (f).

High-frequency vibration or scraping can be monitored by changing the mode of operation of the sensor to monitor only signals at the known location.

If a compliant dielectric substrate is used, the force between the object and the transmission line can be measured from the value determined in (b) or (f).
Claims

1. A method of detecting or analysing an object or other discontinuity in a medium in the vicinity of a transmission line, the discontinuity being such as to cause reflection of a signal transmitted along the transmission line, the method comprising the steps of:

   a) transmitting a signal along the transmission line;

   b) monitoring the transmission line for any reflections of the signal;

   c) generating an analysis window of time if the magnitude of a given characteristic of the reflected signal is greater than a predetermined threshold value; and

   d) analysing the reflected signal received during the period of an analysis window to provide the required information on the discontinuity.

2. A method according to claim 1 in which the duration of the analysis window corresponds to the length of time during which the magnitude of said characteristic is greater than said threshold.

3. A method according to claim 1 or claim 2 in which the given characteristic is the differential of the signal
with respect to time.

4. A method according to claim 1, claim 2 or claim 3, in which the required information is an indication of the position along the transmission line of the discontinuity, and in which the analysis of the reflected signal comprises determining a reception time at which a given point on the reflected signal is received, said indication being obtained from a calculation of the time delay between a start time, when the transmitted signal is applied to the transmission line, and said reception time.

5. A method according to claim 4, in which the part of reflected signal corresponding to the discontinuity gives rise to only one analysis window, and in which the given point on the reflected signal is determined by differentiating the latter with respect to time and ascertaining the time at which the differential is at a pre-determined value.

6. A method according to claim 4, in which the reflected signal gives rise to more than one analysis window and in which the point on the reflected signal is determined by taking the second differential with respect to time of the reflected signal, and finding an average of the respective times in the analysis windows when the second derivative is at a predetermined value.

7. A method according to claim 5 or claim 6, in which the predetermined value is zero.

8. A method according to claim 5, in which an indication of the extent of the discontinuity is obtained by
ascertaining the spread of times at which the second differential is at a predetermined value.

9. A method according to any of claims 4 to 8, in which an initial reflected signal is produced as the transmitted signal is applied to the transmission line, said initial reflected signal being of sufficient magnitude to generate a reference window, wherein the start time is determined by differentiating the initial reflected signal with respect to time, and ascertaining the time at which the differential is at a pre-determined value, within said reference window.

10. A method according to claim 9, in which the pre-determined value is zero.
Fig. 6
INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 90/00930

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all)

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC*: G 01 R 27/06, G 08 B 13/24

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IV. CERTIFICATION

Date of the Actual Completion of the International Search 17th September 1990

Date of Mailing of this International Search Report 09.10.90

International Searching Authority EUROPEAN PATENT OFFICE

Signature of Authorized Officer R.J. Eernisse

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ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO. GB 9000930 
SA 37841 

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