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(54) **Apparatus for cathodic protection of steel reinforced concrete structures and method**

(57) The invention relates to an apparatus for cathodic protection of steel reinforced concrete structures. The apparatus comprises an electrical source for generating an electrical signal, wherein the electrical source is provided with a first output terminal for connection with a cathode structure for contacting a steel segment of the

reinforced concrete structure and with a second output terminal for connection with an anode structure for contacting a concrete surface of the concrete structure. Further, the electrical signal is a pulse shaped current and the electrical source is directly current controlled.

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## Description

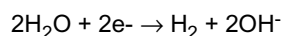
**[0001]** The invention relates to an apparatus for cathodic protection of steel reinforced concrete structures, comprising an electrical source for generating an electrical signal, wherein the electrical source is provided with a first output terminal for connection with a cathode structure for contacting a steel segment of the reinforced concrete structure and with a second output terminal for connection with an anode structure for contacting a concrete surface of the concrete structure.

**[0002]** Corrosion prevention and protection techniques have been a focus of interest for decades in the field of civil engineering. The corrosion of steel in concrete is essentially an electrochemical process, where at the anode iron is oxidized to iron ions that pass into the pore solution and at the cathode oxygen is reduced to hydroxyl (OH<sup>-</sup>) ions. Anode and cathode form a short-circuited corrosion cell, with the flow of electrons in the steel and of ions in the pore solution of concrete.

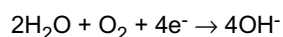
**[0003]** Cathodic protection has been found to be a proven method and working technique to stop corrosion in reinforced concrete structures. The polarization of the steel reinforcement is achieved by supplying impressed direct current to the steel embedded in concrete structures. The repulsion of aggressive anions (e.g. chloride) which takes place along with the protection itself is a beneficial one as far as the corrosion risk of the steel is concerned.

**[0004]** The idea of cathodic protection is to artificially shift the potential of a metal so that it becomes either immune or passive. In sacrificial cathode protection, a galvanic cell is set up by connecting the steel to a more reactive metal, usually zinc. The zinc then undergoes the anodic reaction and corrodes whilst the steel is rendered entirely unreactive because the whole surface undergoes the cathodic reaction and that the iron no longer dissolves.

**[0005]** With impressed direct current cathodic protection, the steel is connected to the negative terminal of an electrical power supply, forcing it to undergo a cathodic reaction. If the potential of the steel is negative enough to make it immune, the cathodic reaction becomes a process whereby water is broken down and hydrogen is liberated as follows:



This situation would normally be avoided in concrete since the pH is high and it is possible to re-establish passivity by applying a somewhat less negative potential. This consumes considerably less current and so reduces the cost. The cathode reaction is then



and OH<sup>-</sup> help to maintain the conditions necessary for passivity.

**[0006]** However, the concentrations of alkali ions in the vicinity of the reinforcement will increase as cations will migrate towards the negatively charged steel surface, leading to a variety of side effects. For example, the increased cation concentrations (K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>) at the steel-paste interface are reported to cause bond degradation between steel and concrete. So, caution should be bestowed on current densities and protection regimes.

**[0007]** Moreover, along with ion migration and diffusion due to the cathodic protection current, the heterogeneities and instabilities inherent in the concrete material may lead to non-uniform distribution of the cathodic protection current and thus result in localized overprotected areas. The overprotection current will result in alkali ions accumulation on the steel/rebar interface, thus causing softening of the C-S-H gel, possible alkali silica reaction (ASR) and loss of bond strength. On the other hand, overprotection current will cause increased hydrogen evolution reactions on the steel surface and lead to hydrogen embrittlement in case of prestressed steel reinforcement. Thus, ordinary impressed cathodic protection has been seldom applied to prestressed concrete structures. In addition, cathodic protection current is found to induce structural deformations in the bulk concrete, inducing micro-cracking and unfavorable pore structure alterations.

**[0008]** In short, main negative effects of cathodic protection comprise bond strength degradation, i.e. loss of adhesion at the steel/concrete interface, coarsening the pore structure and particularly in the interfacial transition zone (ITZ), thus yielding micro-cracks due to the current flow, alkali silica reaction (ASR) or hydrogen embrittlement of pre-stressed steel in concrete structures.

**[0009]** It is an object of the invention to provide an apparatus for cathodic protection of steel reinforced concrete structures, wherein the disadvantages identified above are reduced. In particular, the invention aims at obtaining an apparatus for cathodic protection of steel reinforced concrete structures, wherein corrosion processes are counteracted while overprotection is avoided. Thereto, according to the invention, the electrical signal is a pulse shaped current and the electrical source is directly current controlled.

**[0010]** By applying an electrical pulse shaped current, it has surprisingly been found that sufficient polarization of the steel surface is obtained, thus providing conditions in which corrosion is thermodynamically impossible to occur. By delivering roughly 50% of the electrical energy compared with the conventional direct current technique, a substantially equal corrosion protection is obtained, thereby reducing power supply costs. Moreover, the pulse regime achieves sufficient protection while overprotection is avoided and negative side effects are lowered.

**[0011]** By directly controlling the current of the electrical signal the above-mentioned side effects of cathodic protection techniques are even further reduced, especially if the rise time of the pulsed current is larger than approximately 100 A/m<sup>2</sup>s. Preferably, the rise time of the pulsed electrical current is approximately 1000 A/ m<sup>2</sup>s. However, other values are also applicable, such as 10.000 A/ m<sup>2</sup>s.

**[0012]** As an example, the negative side effects on the concrete bulk microstructure and/or on the steel/paste interface are lowered, thus reducing the extent of bond strength degradation that normally accompanies cathodic protection applications. Also negative side effects on the concrete microstructure in terms of less detrimental effects on microstructural properties as porosity, pore size distribution and properties of the interfacial transition zone between paste and aggregate are lowered, the last being of significant importance for the electrolytic path in the system and for the manner of current distribution.

**[0013]** The research reveals higher effectiveness for the pulse cathodic protection in enhancing the aggressive (chloride) ion migration towards the anode (MMO titanium mesh used) and in reducing the aggressive ion concentration around the cathode (i.e. the steel bar under protection). The pulse technique achieves sufficient steel polarization ( $\leq -900$  mV versus saturated calomel electrode (SCE) for the reinforced concrete) and initial terminal voltage with the same time constant (for the plain concrete) as the steady direct current approach. Moreover, the use of a pulsed electrical signal is found to be less detrimental to the bulk concrete microstructure with respect to porosity, pore connectivity and micro-cracking.

**[0014]** It is noted that an American patent publication US 5 324 405 discloses an apparatus for protecting metal structures such as pipelines or well casings in a conductive medium such as the ground. A driving circuit provides a pulsed signal which is voltage controlled.

**[0015]** Further, it is noted that the apparatus according to the invention can be employed not only in the context of maintenance and/or repair of steel reinforced concrete structures, but also in the case of corrosion prevention of such structures. In the latter case, the pulse cathodic protection can be applied in a more economic and less detrimental method compared to conventional impressed direct current techniques.

**[0016]** As the apparatus according to the invention reduces side effects of cathodic protection techniques, it is also applicable to pre-stressed concrete. Further, it also addresses prevention, improved protection and better performance of reinforced concrete systems in terms of service life and durability issues.

**[0017]** Advantageously, the electrical pulsed current is periodic and has a duty cycle in the range between approximately 1% and approximately 50%. Preferably, the duty cycle is less than 25%, e.g. 12%. To maintain the desired electrical energy, a decrease of the duty cycle with 50% is compensated by doubling the current, so that the product of the pulse amplitude and the pulse duration remains approximately constant.

**[0018]** Further, the invention relates to a method.

**[0019]** Other advantageous embodiments according to the invention are described in the following claims.

**[0020]** By way of example only, an embodiment of the present invention will now be described with reference to the accompanying figures in which

Fig. 1 shows a schematic view of an apparatus according to the invention;

Fig. 2 shows a graph with current pulse patterns;

Fig. 3 shows a view of an interfacial transition zone under prior art conditions; and

Fig. 4 shows a view of an interfacial transition zone using the apparatus of Fig. 1.

**[0021]** The figures are merely schematic views of preferred embodiments according to the invention. In the figures, the same reference numbers refer to equal or corresponding parts.

**[0022]** Figure 1 shows a schematic view of an apparatus 1 for cathodic protection of steel reinforced concrete structures according to the invention. The apparatus comprises an electrical source 2, which can be implemented as a voltage or current source. The electrical source 2 is provided with at least two output terminals, viz. a first, negative output terminal 3 which is connected with a cathode structure 4 and a second, positive output terminal 5 which is connected with an anode structure 6.

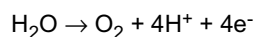
**[0023]** Further, Figure 1 shows schematically a reinforced concrete structure 7, such as a part of a bridge or another civil engineering construction. The structure 7 comprises steel rebars 8 which are at least partially embedded in concrete 9. In stead of rebars 8 also other steel structures could be used, such as meshes.

**[0024]** The cathode structure 4 electrically contacts a steel rebar 8, while the anode structure 6 electrically contacts a concrete surface of the reinforced structure 7.

**[0025]** During operation, the electric source 2 generates a pulsed electrical current which is fed to the output terminals 3, 5. As a consequence, the pulsed electrical current is impressed to the reinforced concrete structure 7 for protection purposes against corrosion effects.

**[0026]** Preferably, the anode structure 4, connected to the positive terminal of the power supply, is chosen to be a relative non-reactive conductor such as carbon or titanium so that its corrosion rate is low. The anode reaction then

generates oxygen and acid ( $H^+$ ) as follows:



The current densities normally encountered in cathode protection systems are sufficiently low for the amount of acid generated to be safely taken up by the normal alkalinity of the concrete.

**[0027]** The dominant corrosion products in the concrete structure protected by pulse cathodic protection are cotton-ball like goethite, as well as whiskey and delicate iron oxychlorides with a linear dimension of less than 5  $\mu m$ . In addition, a relatively compact and dense substrate composed of high-valent iron oxides (hematite, maghemite and magnetite) are formed in the case of cathodic protection, leading to a more adherent and efficiently protective layer on the steel surface. In contrast, iron oxychlorides of lamellar type are formed at 20  $\mu m$  scale in the freely corroding concrete, which tend to induce cracking and promote the diffusion of chloride ions. The favorable morphology (e.g. lower crystallinity) of corrosion products in the pulse protected mortars can be attributed to the relatively high pH value and lower salinity (i.e., lower concentration of chloride ions) in the concrete subjected to pulse cathodic protection. The beneficial microstructural alterations result in better corrosion resistance of the protected concretes, and turn out to be the mechanisms underlying the efficiency of pulse cathodic protection techniques.

**[0028]** Further, the electrical source is directly current controlled. In this process, the current is adjusted to a pre-determined current curve in dependence of a current measurement of the current that is generated by the electrical source 2. By employing an electrical pulsed current there is a favourable charge-discharge cycling, so that ions do not accumulate. This might be a physical cause in favour of the ease of ion migration mechanisms, providing a relatively better performance of the pulse regime with respect to the direct current approach.

**[0029]** The current generated by the electrical source 2 is substantially a periodic block signal with a rise time of approximately 10 mA/10  $\mu s$ , or 1000 A/s. It is noted that the driving circuit disclosed in US '405 generates a current pulse with a much lower rise time, as the circuit is voltage controlled. As a consequence, the system disclosed in US '405 does not lead to the combination of counteracted corrosion processes while overprotection is avoided, anyway not in the extend of the apparatus according to the invention. Preferably, the frequency of the block signal is approximately 1 kHz. However, other frequencies could also be applied, e.g. in a range between approximately 100 Hz and approximately 100 kHz, such as 10 kHz. As indicated above, the quality of the rise time of the block signal is important for the desired effect of the apparatus according to the invention.

**[0030]** Figure 2 shows a graph with current pulse patterns as a function of time which are generated by the current controlled electrical source 2. All pulse patterns shown in Figure 2 are periodic having a frequency of  $(t_4 - t_0)^{-1}$ . The pattern having a bold line 20 is a pulsed signal with a duty cycle of approximately 50%. Further, the pattern having a normal line 21 is a pulsed signal with a duty cycle of approximately 25%. The amplitude of the latter signal is approximately twice the amplitude of the first signal, so that the delivered electrical energy per cycle remains substantially the same. Then, the pattern having a broken line 22 is a pulsed signal with a duty cycle of approximately 12.5%. Again, the latter signal has an amplitude which is approximately twice the amplitude of the second signal. Obviously, also other duty cycles can be employed.

**[0031]** Moreover, microstructural investigations (SEM, EDAX, XRD) have revealed favorable chemical composition and morphologies of the corrosion products and better concrete performance in the case of pulse regime. The crystallinity, morphological aspects and spatial distribution of the corrosion and hydration products (characterized by quantitative image analysis on microlevel) provided supporting experimental evidences. Chemical analysis, performed for plain and reinforced concrete under various technical conditions, proved the much higher efficiency of the pulse regime in terms of lowering the aggressive ion concentrations in the vicinity of the rebars.

**[0032]** As an example, Figures 3 and 4 shows the difference of the conventional direct current approach (Figure 3) and the pulsed current approach (Figure 4). In Figure 3 an interfacial transition zone under prior art conditions is shown as a SEM image with a magnification of 1000 x. Obviously, an enlarged gap, the interfacial transition zone 32, is visible between aggregate 30, such as sand or stone, and cement paste 31. The enlarged gap is a side effect of the direct current applied to the concrete structure. Figure 4 is also a SEM image with a magnification of 1000 x showing an interfacial transition zone. However the zone shown in Figure 4, the gap 42 between aggregate 40 and cement paste 43, belongs to a concrete structure that is treated with an apparatus according to the invention. The gap 42 is smaller, thus indicating that the method according to the invention has less side effects than the prior art method.

**[0033]** The invention is not restricted to the embodiments described herein. It will be understood that many variants are possible. Instead of employing a single pair of electrodes, also a multiple set of electrodes of either the cathode structure or the anode structure, or both, could be used.

**[0034]** Further, the anode structure might contact the concrete structure by means of an external electrode e.g. as shown in Figure 1, or by means of an electrode embedded in the concrete structure.

**[0035]** Other such variants will be obvious for the person skilled in the art and are considered to lie within the scope of the invention as formulated in the following claims.

Claims

1. An apparatus for cathodic protection of steel reinforced concrete structures, comprising an electrical source for generating an electrical signal, wherein the electrical source is provided with a first output terminal for connection with a cathode structure for contacting a steel segment of the reinforced concrete structure and with a second output terminal for connection with an anode structure for contacting a concrete surface of the concrete structure, wherein the electrical signal is a pulse shaped current and wherein the electrical source is directly current controlled.
2. An apparatus according to claim 1, wherein the rise time of the pulsed current is larger than approximately 100 A/m<sup>2</sup>s.
3. An apparatus according to claim 1 or 2, wherein the pulsed current is substantially a periodic block signal.
4. An apparatus according to any previous claim, wherein the frequency of the pulsed current is in a range between approximately 100 Hz and approximately 100 kHz.
5. An apparatus according to any previous claim, wherein the duty cycle of the pulsed current is in the range between approximately 1% and approximately 50%.
6. A method for cathodic protection of steel reinforced concrete structures, comprising the steps of:
  - contacting a steel segment of the concrete structure by means of a cathode structure;
  - contacting a concrete surface of the concrete structure by means of an anode structure;
  - connecting the cathode structure and the anode structure with a first and a second output terminal, respectively, of an electrical source for generating an electrical signal;
  - driving the electrical source to generate a pulsed electrical signal; and
  - directly controlling the current of the electrical signal.

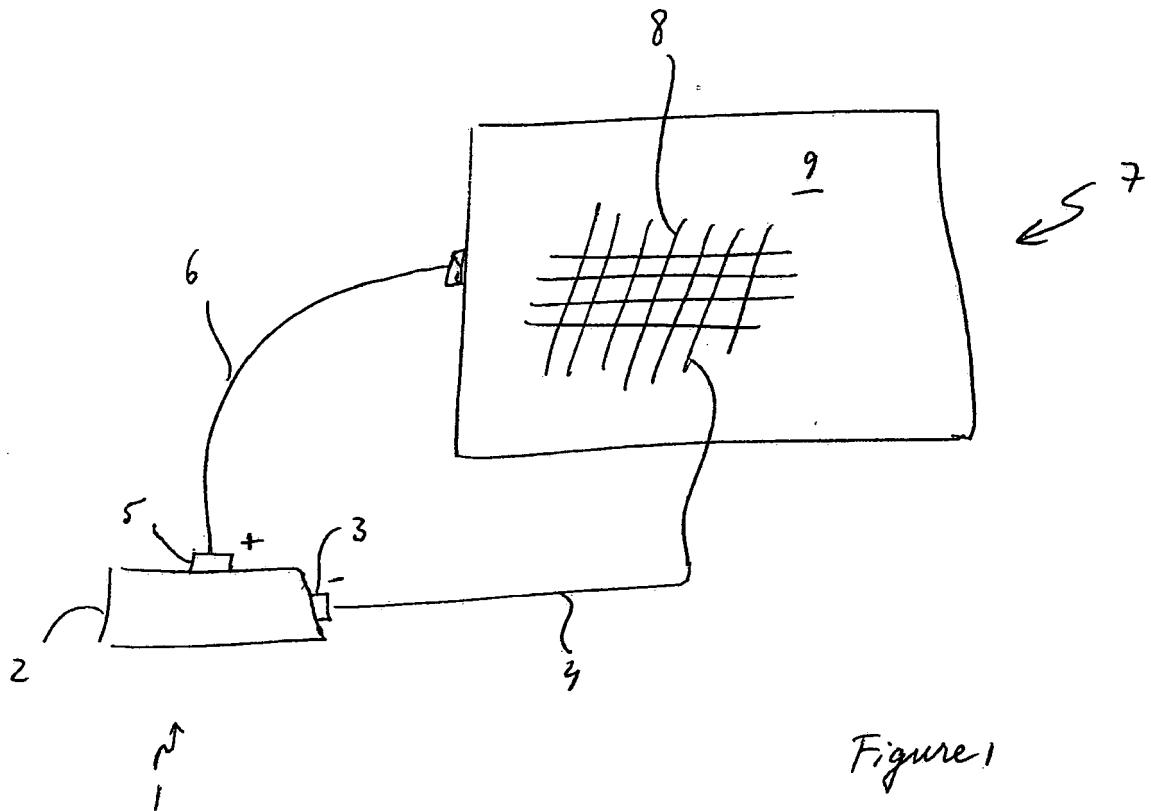


Figure 1

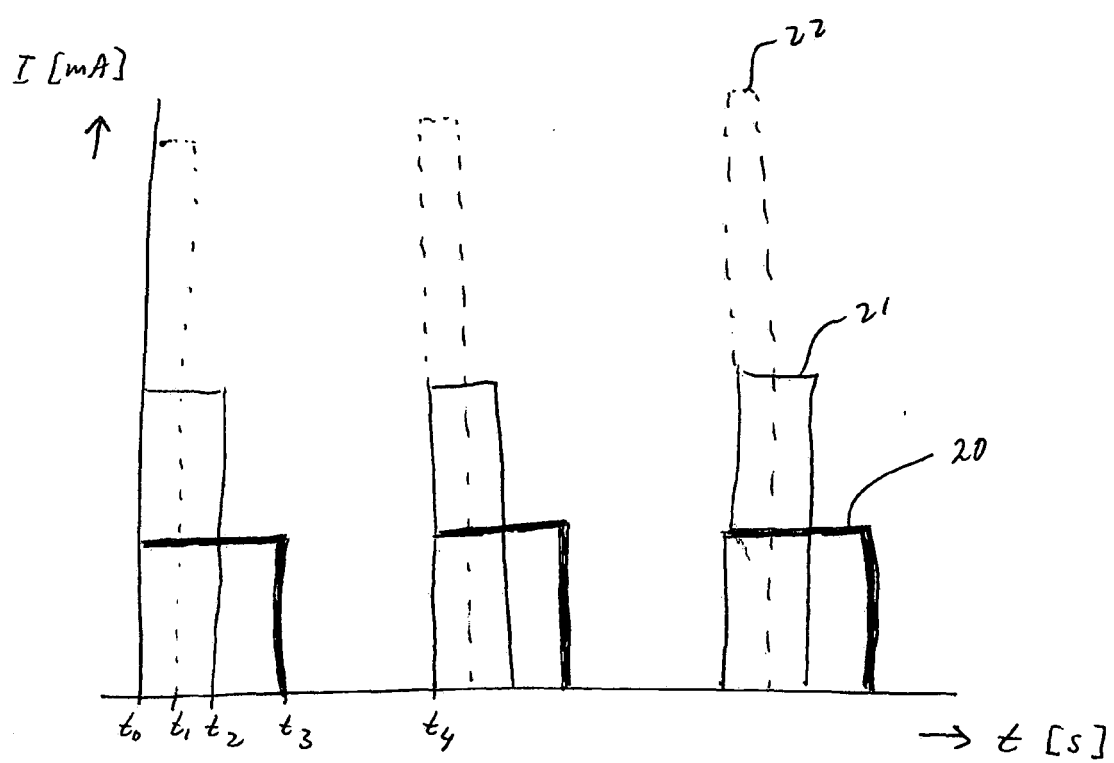


Figure 2

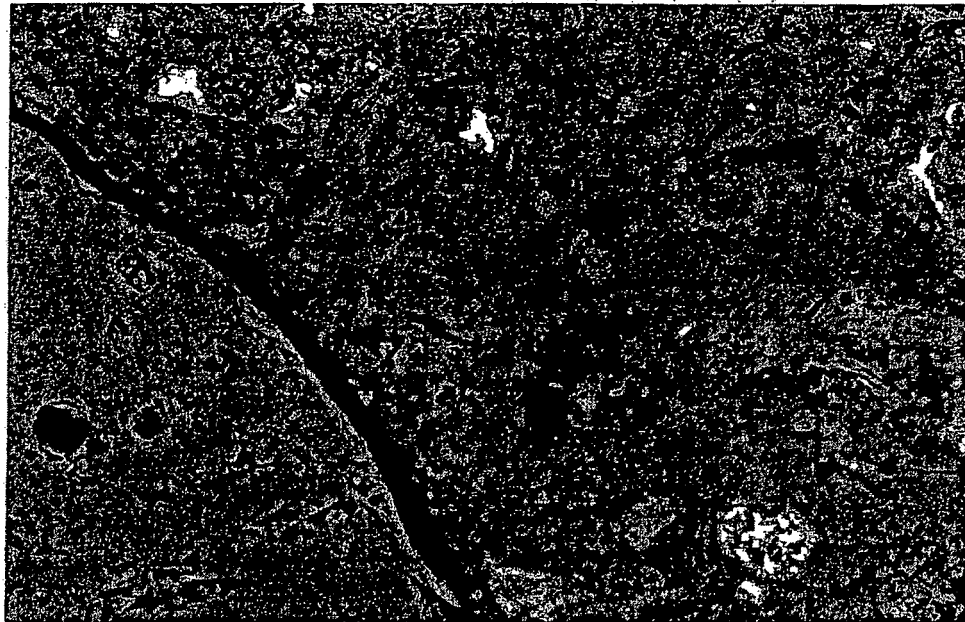


Figure 3



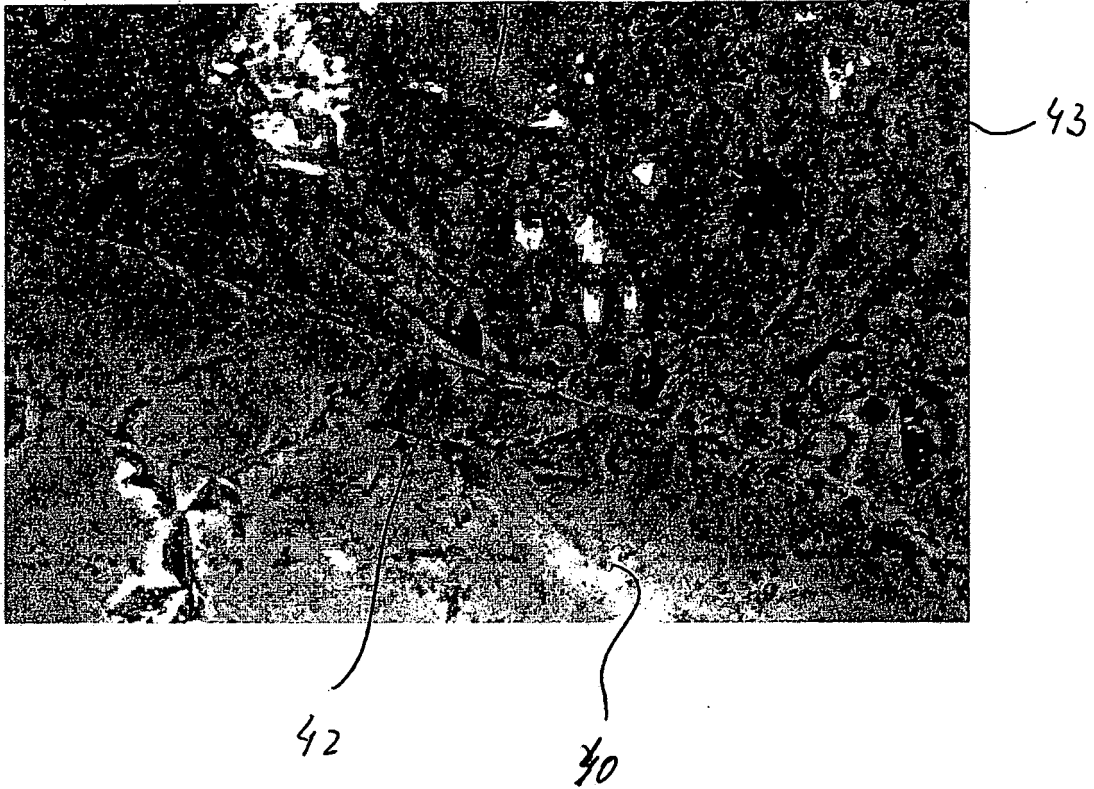


Figure 4



European Patent  
Office

# EUROPEAN SEARCH REPORT

Application Number  
EP 05 07 7395

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Place of search The Hague		Date of completion of the search 17 March 2006	Examiner Desbois, V
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**ANNEX TO THE EUROPEAN SEARCH REPORT  
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