

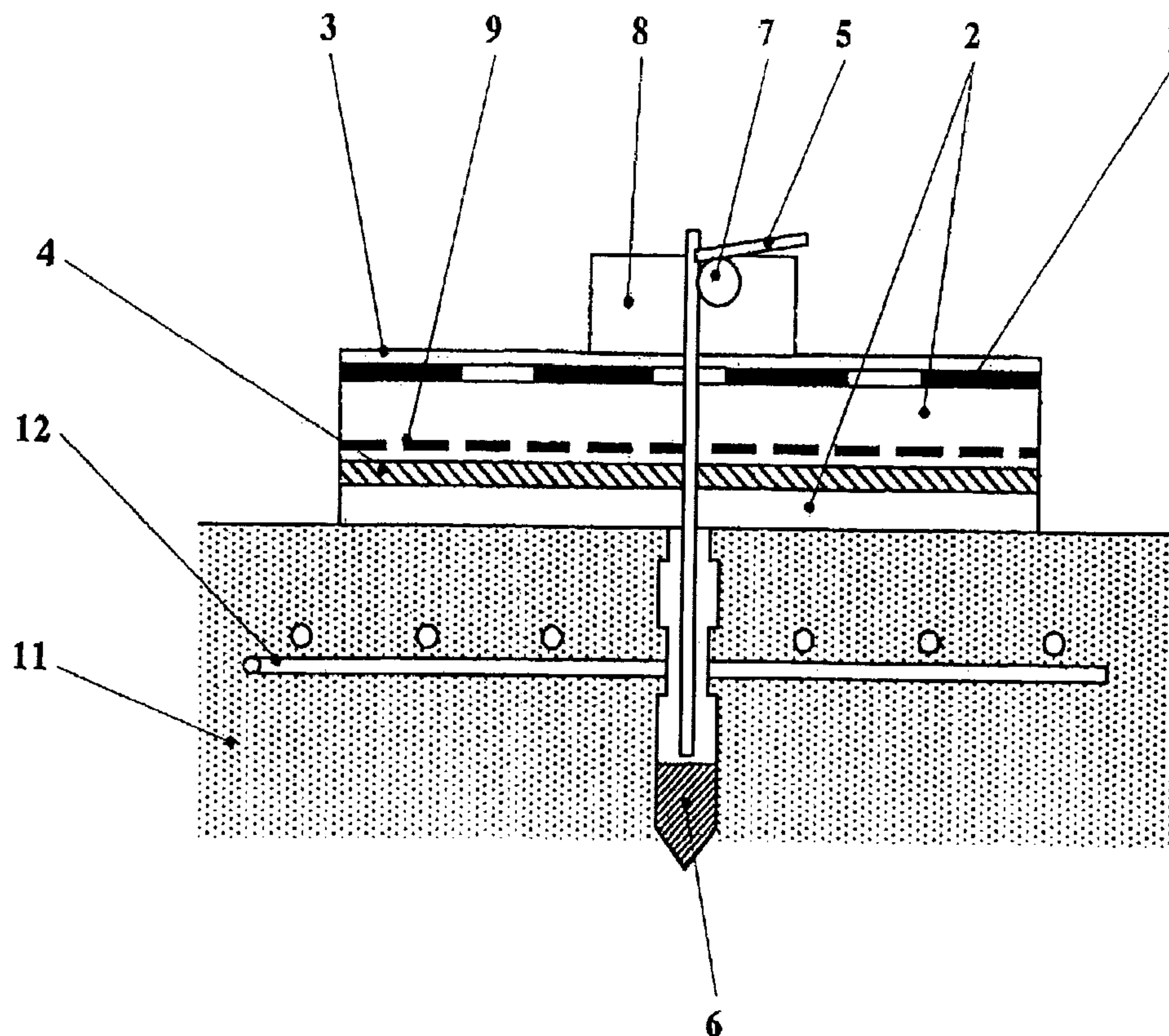


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(54) Titre : ELECTRODE COMBINEE POUR LA REGENERATION ELECTROCHIMIQUE DU BETON ARME
ENDOMMAGE PAR LA CORROSION, ET PROCEDE DE COMMANDE Y RELATIF

(54) Title: COMBINATION ELECTRODE FOR THE ELECTROCHEMICAL RESTORATION OF CORROSION-DAMAGED
REINFORCED CONCRETE AND CORRESPONDING METHOD FOR CONTROLLING THE SAME



(57) Abrégé/Abstract:

The invention relates to a combination electrode for the restoration of corrosion-damaged reinforced concrete and a method for controlling the same. The combination electrode consists of a dimensionally stable electrode (1); a pre-fabricated, re-usable



(57) Abrégé(suite)/Abstract(continued):

electrolyte reservoir (2); means for protecting against evaporation (3); a pre-fabricated, interchangeable, anionic ion exchange element (4); a central fastening element comprising an anchor, anchor rod and a rapid-clamping tappet (5); a reference electrode (6) on the anchor head; a humidification device (7); a power switching element for anodic regulation (8); a measuring system for determining the state of the ion exchange element (9), in addition to electric connections for the reference cell. The method consists of subdividing the concrete surface to be restored into grid surfaces of equal size; assembling the composite electrodes on the grid surfaces; carrying out control measurements on each grid surface; setting initial values; determining measurement, regulation and termination criteria for each individual grid surface; supplying direct current to the grid surface whilst monitoring the reference potential and the potential in the chloride sensor and the disconnection flank during the course of the restoration, whereby the direct current output during the course of said restoration is regulated by pulse width modulation in such a way, that it corresponds to the energy requirements of the grid surface.

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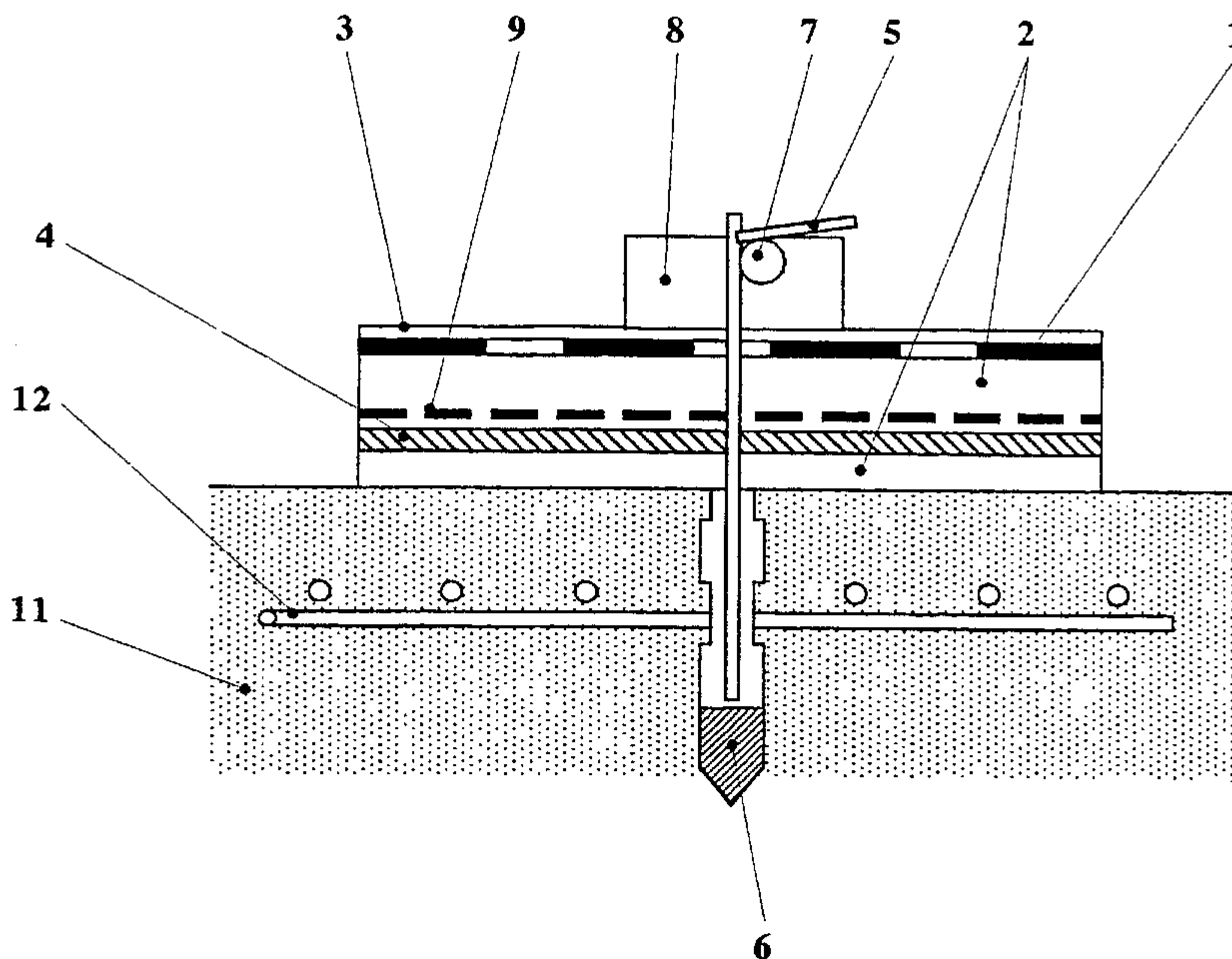
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(54) Title: COMBINATION ELECTRODE FOR THE ELECTROCHEMICAL RESTORATION OF CORROSION-DAMAGED REINFORCED CONCRETE AND CORRESPONDING METHOD FOR CONTROLLING THE SAME

(54) Bezeichnung: KOMBINATIONSELEKTRODE FÜR DIE ELEKTROCHEMISCHE SANIERUNG VON KORROSIONSGESCHÄDIGTEM STAHLBETON UND VERFAHREN ZU DEREN ANSTEUERUNG



(57) Abstract: The invention relates to a combination electrode for the restoration of corrosion-damaged reinforced concrete and a method for controlling the same. The combination electrode consists of a dimensionally stable electrode (1); a pre-fabricated, re-usable electrolyte reservoir (2); means for protecting against evaporation (3); a pre-fabricated, interchangeable, anionic ion exchange element (4); a central fastening element comprising an anchor, anchor rod and a rapid-clamping tappet (5); a reference electrode (6) on the anchor head; a humidification device (7); a power switching element for anodic regulation (8); a measuring system for determining the state of the ion exchange element (9), in addition to electric connections for the reference cell. The method consists

of subdividing the concrete surface to be restored into grid surfaces of equal size; assembling the composite electrodes on the grid surfaces; carrying out control measurements on each grid surface; setting initial values; determining measurement, regulation and termination criteria for each individual grid surface; supplying direct current to the grid surface whilst monitoring the reference potential and the potential in the chloride sensor and the disconnection flank during the course of the restoration, whereby the direct current output during the course of said restoration is regulated by pulse width modulation in such a way, that it corresponds to the energy requirements of the grid surface.

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Zur Erklärung der Zweibuchstaben-Codes, und der anderen Abkürzungen wird auf die Erklärungen ("Guidance Notes on Codes and Abbreviations") am Anfang jeder regulären Ausgabe der PCT-Gazette verwiesen.

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(57) Zusammenfassung: Die Erfindung betrifft eine Kombinationselektrode für die Sanierung von korrosionsgeschädigtem Stahlbeton und ein Verfahren zu deren Ansteuerung. Die Kombinationselektrode besteht aus einer dimensionsstabilen Elektrode (1); einem vorgefertigten, wiederverwendbaren Elektrolytspeicher (2); Verdunstungsschutz (3); einem vorgefertigten, wechselbaren, anionischen Ionenaustauscherelement (4); einer Zentralbefestigung mit Dübel, Ankerstange und Exzenter-Schnellspannvorrichtung (5); einer Referenzelektrode (6) am Dübelkopf; eine Befeuchtungseinrichtung (7); einem Leistungsschaltelement zur anodischen Regelung (8); einem Meßsystem zur Zustandsbestimmung am Ionenaustauscherelement (9) sowie elektrischen Anschlüssen für die Referenzzelle. Das Verfahren umfaßt die Unterteilung der zu sanierenden Betonfläche in gleich große Rasterflächen; die Montage der Verbundelektroden an den Rasterflächen; die Durchführung von Kontrollmessungen an jeder Rasterfläche; das Einstellen von Startwerten; das Festlegen von Meß-, Regel- und Abbruchkriterien für jede einzelne Rasterfläche; die Zuführung von Gleichstrom zu der Rasterfläche unter Überwachung des Referenzpotentials während der Laufzeit der Sanierung, des Potentials am Chloridsensor und der Ausschaltflanke, wobei die Gleichstromleistung während der Laufzeit der Sanierung durch Pulsweitenmodulation so eingestellt wird, dass sie dem Energiebedarf der Rasterfläche entspricht.

Combination Electrode For The Electrochemical Restoration Of Corrosion-Damaged Reinforced Concrete And Corresponding Method For Controlling the Same

The invention relates to a combination electrode for the electrochemical restoration of corrosion-damaged reinforced concrete and a method of controlling the same.

Mineral based construction materials used in construction technologies, such as, concrete, cement, or mortar, are customarily reinforced with steel elements that are embedded for this purpose into the mineral-based construction material. In the case of a properly manufactured concrete element, these steel elements are coated with such a thick concrete layer that the steel element is, as a rule, permanently protected against corrosion. The corrosion protection of the concrete layer is based on the alkalinity of the water that is found in the pores of the concrete and has a pH-value greater than 12.5. Under these conditions, a thin, adherent oxide film forms on the surface of the steel. This oxide film in practice completely prevents a corrosion of the steel element. For this reason, reinforced concrete can be used for external components that are subject to weather conditions. Under unfavorable conditions, however, especially in the case of faulty construction work and, particularly, saliferous environmental conditions, the corrosion protection of the reinforcement can be impaired. In such a case, when carbon dioxide from the air reacts with the alkaline components of the cement, the concrete undergoes carbonization. The pH-value then drops, so that the protection from corrosion no longer exists. Another frequently occurring cause for corrosion is the ingress of chlorides into the concrete, for example, when concrete components are used as a roadway or in the vicinity of a roadway where de-icing salt is used. Both processes begin on the surface of the concrete and continue to work their way into the interior of the concrete to the steel components embedded therein, during the course of which oxide film dissolves. In order to prevent the destruction of the concrete due to spalling as a result of voluminous corrosion products, the concrete containing the chloride must be replaced, or the chloride itself must be removed from the concrete.

Various methods are known for replacing contaminated material. With these physical methods, the contaminated material is removed and replaced with fresh concrete. This, however, requires extensive effort and is, thus, an expensive solution,. Furthermore, it is effective only in those areas that have already been recognized as damaged.

For this reason, a method is proposed in which the chloride is removed electrochemically from the concrete by means of ionic migration. In this way, the chloride concentration in the concrete is drastically reduced, so that it is no longer necessary to replace the concrete. The method described by J. E. Slater in *Materials Performance*, 1976 (pp. 21-26), encompasses the application of an electrical potential between the interior reinforcement and a surface electrode that is submerged in a liquid electrolyte located on the surface of the concrete. The surface electrode thereby forms the positive pole of the electrical field which causes the negatively charged chloride ions that are contained in the concrete to migrate through the concrete, exit the concrete, and reach the electrolyte. The chloride ions are oxidized to gaseous chlorine in the electrolyte at the positive electrode, or they react chemically with components that are contained in the electrolyte. The method proposed by Slater, however, has several disadvantages: For one, this method requires that voltages between 100 and 120 V be applied. Such high voltages, which must be applied over a period of 24 hours in order to remove approximately 90% of the chloride from the concrete, are unacceptable for technical safety reasons. Furthermore, the costs thereby incurred can surpass even those of conventional technologies. For another, the liquid electrolyte used is restrained by dams that must be built on the surface of the concrete. The method can therefore be applied only to horizontal concrete surfaces. This restriction results in significant expenditure for the preparation of the chloride removal, and moreover greatly restricts the applicability of the method. A further disadvantage of this method is the fact that the non-homogeneities present in the reinforced concrete (concrete covering, concrete density, moisture content, reinforcement density relative to the surface of the concrete), which in the case of a desired treatment of large-surface construction

components can lead to a significantly varying process intensity, are not particularly taken into account.

With respect to the latter mentioned problem, DE 4 229 072 A1 proposes an electrolyte reservoir with a resistance of $R \gg 0$, so that partial overheatings, e.g., with a single protruding reinforcement with the then resulting small R_{Concrete} , are compensated by the $R_{\text{Electrolyte}}$. The fact that the process peaks are automatically cut off only, without feedback control occurring in the case of a partial hypofunction (R_{concrete} large), is a disadvantage of this solution.

US 5,228,959 proposes as the electrolyte an adherent layer that can be applied to vertical surfaces or even to the undersides of concrete elements and that adheres to the same. An electrode that constitutes the positive pole of the electrical system is embedded in the adherent layer. When the method is complete, that is, when the level of chloride contamination has been reduced to a desired level, the adherent layer, as well as the electrode, is removed from the concrete surface. The individual steps of the method comprise applying a removable adherent electrolyte layer onto the surface of the concrete; applying a d.c. voltage between the reinforcement and the electrode, in order to effect migration of the negative ions; interrupting the applied voltage and removing the adherent layer when the desired level of ion migration has been achieved; periodically measuring the difference in potential between the reinforcement and the reference electrode and temporarily interrupting the d.c. voltage when the difference in potential indicates the formation of hydrogen. Although this method offers a number of advantages when compared to the method proposed by Slater, it does have the disadvantage that the electrochemical system can be used only once; re-use is impossible. Even though it states in US 5.228.959 that the used material can be easily and inexpensively disposed of, this is no longer acceptable from the viewpoint of increasingly restrictive environmental standards and increasing disposal costs. Furthermore, the release of chlorine that is linked to the use of the method is extremely harmful to the environment.

This method has been modified in several patent applications. EP 0 398 117 A1, for example, proposes a cellulose pulp as the material for the adherent electrolyte layer. The cellulose pulp can be premixed in a nozzle with water or another solution, such as calcium hydroxide, and sprayed onto the surface of the area to be treated. For the electrode, this application also proposes a ferriferous material that is reactive in the presence of chlorine, in order to minimize the release of free chlorine into the environment. This has the advantage of releasing less chlorine into the environment, but the disadvantage of not completely eliminating the formation of chlorine. Furthermore, the electrode disintegrates in the course of the application of the method so that even for this reason, the method can be used only once.

The aim of the present invention is therefore to propose a means for electrochemical restoration of corrosion-damaged reinforced concrete that overcomes the aforementioned disadvantages of the methods of the prior art. The task, therefore, is to propose an economical solution that is associated with minimal technical effort, that can be applied several times, not just once, and that is optimally adjusted to the non-homogeneities in the component that is to be restored.

According to the invention, this is achieved by means of a combination electrode that comprises a dimensionally stable electrode as the anode; a prefabricated, reusable electrolyte reservoir; a means for protecting against evaporation; a prefabricated, exchangeable, anionic ion exchanger element; a central fastening with an anchor, an anchor rod, and an eccentric quick-clamping device; a reference electrode on the anchor head; a wetting device; a power-switching device for anodic regulation; a measuring system for determining the condition on the ion exchanger element; as well as electrical connections for the reference electrode, etc. The dimensionally stable electrode, the means for protecting against evaporation, the electrolyte reservoir, and the ion exchanger can thereby be connected to each other in the form of a sandwich construction.

The combination electrode has a small area (ca. 0.6 x 0.6 m), relative to the component to be restored.

The combination electrode according to the invention is advantageous in that it can be industrially prefabricated. Moreover, it contains all components that are required for active process control. The multipart constructed combination electrode allows reactivation of the ion exchange material for reprocessing. An essential advantage of the invention is that no active chlorine is formed. The chloride ions extracted from the concrete are bonded to the ion exchange material, from which they can be removed by the reactivation of this material. The combination electrode is therefore reusable. The electrode is not self-adherent.

The dimensionally stable electrode is preferably made of surface-modified titanium, tantalum, or similar materials.

The electrolyte reservoir comprises a fibrous, mineral-based material, preferably glass mat. It thus behaves chemically neutral under extreme acidic or caustic conditions, and discolorations on the surface of the concrete are avoided; furthermore, it is geometrically constant and has good water-storage capacity.

The ion exchanger is so embodied that anionic ion exchanger material is attached to a perforated carrier and prefabricated in such a way that it can be inserted as a layer in the combination electrode, preferably between electrolyte reservoir and electrode. The electrode can herewith be used in all installation positions and be quickly and easily serviced when the ion exchanger is exhausted.

A distinguishing feature of the sensory technology for the on-line status control of the ion exchanger material is a measuring system that is assembled between the ion exchanger layer and the dimensionally stable electrode for the purpose of monitoring the consumption status. The measuring system is cyclically scanned by means of a computer. An auxiliary electrode or a chloride sensor is thereby integrated into the combination electrode. When chloride ions strike the auxiliary electrode, a measurable signal is generated.

Fastener, quick-clamping device, and reference electrode are embodied in such a way that a reference cell, with a water-retaining, easily flexible diaphragm (for example, MnO_2 and water-saturated felt), is arranged on a plastic anchor. During

operation, the anchor with the reference electrode is moved forward into a bore hole, which is preferably centrally situated in the electrode area and is a defined distance from the pertinent reinforcement. The sandwich part of the combination electrode is pushed onto the anchor rod and fastened by means of a sleeve that is fitted over it and held fast by an eccentric shaft with lever. The anchor rod has a hollow form for receiving the reference electrode feed line and has a set depth limit.

A more detailed description of the invention, with reference to the attached drawings, follows.

Fig. 1 is a schematic cross-sectional representation of the combination electrode.

Fig. 2 shows a diagonal view of the application of the combination electrode according to the invention.

The multi-component, prefabricated combination electrode that is shown in Fig. 1 comprises the dimensionally stable electrode 1; the prefabricated, reusable electrolyte reservoir 2; the means for protecting against evaporation 3; and the prefabricated, replaceable, anionic ion exchanger element 4, all of which are connected to each other as a sandwich construction. The reference electrode 6 is disposed on the anchor head of the central fastener that includes the anchor, anchor rod, and eccentric quick-clamping device 5. Furthermore, the combination electrode is equipped with a wetting device 7, a power-switching device for anodic regulation 8, a measuring system 9 for determining the condition on the ion exchanger element, as well as (not shown) electrical connections for the reference cell. When using the combination electrode, the anchor with the reference electrode 6 is inserted into a bore hole in the concrete 11, whereby the bore hole is preferably centrally located within the surface of the electrode and a defined lateral distance from the pertinent reinforcement 12.

Fig. 2 shows the combination electrode 13 being used on a concrete element 14 that is to be restored. The surface of the concrete part is divided for this purpose into small sub-areas. Such a sub-area is preferably 60 x 60 cm in size.

The aim of the method for controlling an electrode system is the short-time electrochemical restoration of corrosion-damaged reinforced concrete. The method comprises (1) subdividing into any number of grid areas of equal size the two-dimensional surface of a reinforced concrete structure to be restored; (2) determining the electrochemical, physical, and chemical characteristics by measuring the quiescent potential, measuring the galvanic pulse, recording the progression of the reinforcement of the cover reinforcement, the concrete covering, the pore volume, the moisture, the chloride content, and the depth of carbonization; (3) assembling the combination electrodes on the grid areas; (4) carrying out control measurements on each grid area in order to determine the quiescent potential (E_{Ref}), to check the electrical contacts, and to determine the temporal change of the current as a result of the external voltage (ΔI_{AC}); (5) setting the initial values, which include, for each grid area the terminal voltage between anode and cathode (E_{AC}), the minimum terminal voltage without external voltage ($E_{\text{AC, min}}$), the frequency of the pulse-width modulation (f_{PWR}), the switch-on time of the external voltage (t_{ON}), the switch-off time of the external voltage (t_{OFF}), the minimum cathodic reference potential ($E_{\text{Ref, min}}$), the chloride content at the start of restoration (CL_{Start}), and the targeted chloride content (CL_{End}); (6) determining the measurement, control, and abort criteria for each individual grid area; (7) supplying direct current to the grid area under constant monitoring of the reference potential during the course of restoration, the change in voltage on the chloride sensor, and the switch-off slope, whereby the direct current power supplied during the course of restoration is regulated by pulse-width modulation such that the power corresponds to the energy requirements of the grid area to be restored. The structure to be restored is examined prior to implementation of the method according to the invention with respect to its specific features, such as, the distance of the shell area of the cover reinforcement as working electrode, as well as to determine the average and minimum concrete covering at each grid area. The control measurements simultaneously serve to check the electrical connections, as well as to obtain a low electrolyte resistance in the concrete by ensuring sufficient component moisture. In Step (1), the two-dimensional areas of a reinforced concrete structure that is to be restored are preferably partitioned into grid areas that are 0.6 x 0.6 m in size. Monitoring the

change in voltage on the chloride sensor in Step (7) includes constant polling of an auxiliary electrode, so as to determine the saturation of the ion exchanger. The abort criteria, which are monitored on each grid area throughout the entire course of restoration, are selected from the group that includes the total chloride amount contained in the ion exchanger that corresponds to the difference between the chloride content in the concrete at the start of restoration (Cl_{Start}) and the targeted chloride content (Cl_{End}); the 100 mV criterion that serves to estimate the alkalinity reserve; and the recorded quantity of charge.

When carrying out the method according to the invention, precisely that amount of direct current power that the respective area requires is supplied to each grid area during restoration. This power demand is constantly recalculated for each grid area to be restored. If the capacity of the ion exchanger is exhausted, it can be repeatedly renewed during restoration.

The constant polling of the chloride sensor enables a precise determination of the saturation of the ion exchanger in the combination electrode. If the ion exchanger is saturated, then the restoration method is automatically interrupted for the particular grid area, so that chlorine gas cannot form at the anode. Simultaneously, the chloride amount that corresponds to the take-up capacity of the ion exchanger is included in the process as a computation value.

A reduction of the direct current power of an electrode is achieved by pulse-width modulation. The pulse-width modulation encompasses an on-off controller with the conditions ON and OFF. An effective power at the consumer, i.e., at the grid areas, is obtained by varying the time ratios of the ON and OFF phases. It is not possible to reduce the direct current demand by reducing the direct current power with a conventional longitudinal controller because the unused energy in the controller is converted into heat. Using pulse-width modulation according to the invention prevents this. Aided by the pulse-width modulation and based on the modular design, which enables the individual control of each grid area, the energy demand of each grid area is optimally determined, so that the supplied power can be adjusted to the power demands. The d.c. voltage available for all electrodes of the restoration

surface is switched by the control computer, supplied to the electrodes, and, according to energy demands, regulated as a pulse-width modulated square-wave voltage with minimum power losses. An individual r.m.s. voltage or an individual r.m.s. current results between anode and cathode, the voltage or current being re-measured for each control cycle and optimally adjusted to the kinetic ratios at each electrode. Furthermore, the cathodic potential measured at the reference electrode and falsified by the ohmic resistance of the concrete between the restoration and the reference electrode can be corrected via the control computer by measuring and evaluating the steepness of the switch-off slope on the pulse-width control module at each electrode (IR compensation).

When using the method according to the invention, each grid area or each group of grid areas can be treated as required by the actual degree of damage, due to the modular design of the device used. Each grid area or each group of grid areas can continue to be treated individually by the delay time control, depending on the progress of the restoration. By using the pulse-width modulation, a low-loss power feed and power control are individually obtained for each grid area, as a function of its requirements, thus enabling optimal restoration. Furthermore, additional large-area safety allowances for preventing process overheating are not required, because each grid area is treated with reference to the respective cathodic reference potential. In this way, process reserves are utilized and, furthermore, it is guaranteed that no damages to the structure occur. The fact that the process automatically switches off as soon as the capacity of the ion exchanger for accepting chloride is exhausted is an advantage, as this prevents the formation of environmentally polluting chlorine. Thus, the method is, to a high degree, environmentally friendly, compared to conventional methods.

Furthermore, the invention is characterized by a better reinforcement analysis in conjunction with small-area electrodes, whereby the method is directed at the jacket area of the effective reinforcement and does not—as do the methods of the prior art—make the simplifying and incorrect assumption that the reinforcement area is identical with the concrete surface. The method can be individually adjusted and

optimized, on the basis of known electrode areas, as well as current density distributions.

The pulse-width modulation used according to the invention enables individual and dynamic process control of each individual combination electrode (0.6 x 0.6 m) without greater power losses relative to the otherwise conventional constant or regulated current sources. Furthermore, the method achieves an increase in efficiency by staggering the active times of different combination electrodes in such a way that the maximum capacity of the system can be dimensioned below the total capacity of all combination electrodes. The pulse-width modulation makes it possible to have an r.m.s. voltage for each combination electrode according to the thermodynamic conditions within the reinforcement area that is scanned by the combination electrode. Parameters of the pulse-width modulation are frequency and pulse duty ratio, which, starting from the initial set values, are constantly adjusted during the process. Using pulse-width modulation, it is not necessary to limit the current for the connected combination electrode. For safety reasons, the available d.c. voltage is set at 40 V.

According to the method, the unwound jacket area of the cover reinforcement is, thus, an essential output parameter. The electrode area of the operating electrode (reinforcement, cathode) has previously been determined to be non-destructive. As a result, the current distribution is substantially better measured and optimized than it is with the current line of thinking, which equates the electrode area with the concrete surface and, as a result, can arrive at completely incorrect reference values.

Furthermore, it is currently impossible to perform chloride measurements in the electrical field. The chloride sensor used according to the invention as a threshold switch indicates when the ion exchanger cannot take up additional chloride ions. This allows definite conclusions to be drawn regarding the achieved extraction of chloride. In addition, unintentional formation of chlorine at the anode is prevented, because the aforementioned threshold signal results in the pertinent combination

electrode being switched off. The switched-off condition is maintained until the exhausted ion exchanger is renewed.

The illustrated use of pulse-width modulation makes the function of a switch-off slope of the pulse-width-modulated d.c. voltage applicable for continuous IR correction only when such switch-off slopes are available for evaluation in temporally very rapid successions. Because of the significantly increased dot layer of the IR drop-off measurements (resolved according to place and time), safety limits of the process (avoidance of formation of H_2) can be significantly better utilized, resulting in sustained greater effectivity.

Finally, the method is distinguished by the possibility of parallel local or remote control. As a result, several restoration projects can be worked and managed simultaneously comfortably and conservatively with regard to resources. Using the standardized Ethernet network for both connecting the combination electrodes with cables to the control computer, and also for decoupling additional units, guarantees the highest degree of flexibility and the best connection possibilities. Authorized third parties (general contractors, owners) can thereby access timely information regarding the process.

The proposed method is further explained as follows, using a flow chart shown in Fig. 3. To implement the method, apparatus comprising a combination electrode is used. The electrode is attached to a grid area approximately 0.6 x 0.6 m large on the two-dimensional reinforced concrete surface to be restored. The steel reinforcement contained within the concrete is connected to the grounding conductor. The combination electrode, which has a sensor output and a control input, is connected to sensor electronics via a sensor cable for the purpose of recording measured values and connected to control electronics via a control cable for the purpose of regulating the power, as well as to a direct current bus. Two electronic modules are connected to a control computer via network electronics and an Ethernet network.

The method according to the invention illustrated in Fig. 3 comprises the following steps: The necessary preparations encompass an assessment of the condition of the structure, for example, with regard to the spacing of the reinforcement elements, the partitioning of the concrete surface into individual grid areas, the assembly of the combination electrodes, as well as sufficiently wetting the concrete. Once these preparations have been completed, control measurements are taken for checking the electrical contacts, determining the quiescent potential and change in the current resulting from the external voltage (ΔI_{AC}), i.e., from the extraction current. The change in current ΔI_{AC} is a function of the terminal voltage between the anode and cathode (E_{AC}) and time. If these values correspond to the predetermined values, then the remaining method steps can be performed; otherwise, the values must be readjusted. In the subsequent method step, the initial values are set via control electronics. These are the terminal voltage between anode and cathode (E_{AC} , maximum 40 V), the minimum terminal voltage without external voltage ($E_{AC, \min}$, e.g., 20 V), the OFF terminal voltage between anode and cathode ($E_{AC, \text{off}}$), the frequency of the pulse-width modulation (f_{PWR} , wherein $f_{PWR} = t_{ON} + t_{OFF}$), the switch-on time of the external voltage (t_{ON}), the switch-off time of the external voltage (t_{OFF}), the minimum cathodic reference potential ($E_{Ref, \min}$), the chloride content at the beginning of restoration (CL_{Start} , e.g., 3.0 M%, relative to the cement mass), and the targeted chloride content (CL_{End} , e.g., 0.3 M%, relative to the cement mass). After determining the measurement, control, and abort criteria, direct current is supplied to the grid area. During this process, the control computer continuously checks whether the reference potential at the cathode (E_{Ref}) is greater than the cathodic reference potential ($E_{Ref, \min}$) that has been set as the threshold value (e.g., -1070 mV vs. Cu/CuSO₄). If this is the case, the correction value of the switch-on time ($t_{ON, \text{corr}}$) is set higher than the predetermined switch-on time (t_{ON}) of the external voltage, so that the direct current can continue to be supplied. If the voltage reaches or goes below $E_{Ref, \min}$, then the electrode can be turned off, and the OFF terminal voltage between anode and cathode ($E_{AC, \text{off}}$) checked to see if it is lower than the minimum terminal voltage without extreme voltage ($E_{AC, \min}$). If this is the case before T_{OFF} is completed, then the correction value of the switch-off time ($t_{OFF, \text{corr}}$) is set lower than the switch-off time (t_{OFF}) of the external voltage, so that the

direct current can continue to be supplied. If $E_{AC, OFF}$ is greater than E_{AC} and the reference potential at the cathode (E_{ref}) is the same as the minimum predetermined cathodic reference potential ($E_{ref, min}$), then a check is subsequently performed to assess whether a change in voltage on the chloride sensor (ΔE_{CL}), the so-called "break-through potential", which lies in the millivolt range, is not equal to zero. If ΔE_{CL} is not equal to zero, then the method is interrupted, the ion exchanger is renewed, and, finally, the method is continued while the ΔE_{CL} is rechecked. If ΔE_{CL} is equal to zero and the difference between the chloride content at the beginning of restoration (CL_{Start}) and the targeted chloride content (CL_{End}) is equal to the sum of the eliminated amount of chloride, then the change of the reference potential after the external voltage is switched off, e.g., a minimum of 100 mV/4 hours, is determined. If the value is not undercut, the restoration goal is attained, so that the method is completed. Otherwise, the method is continued.

List of Terms Used

1. dimensionally stable electrode
2. prefabricated, reusable electrolyte reservoir
3. means for protecting against evaporation
4. prefabricated, exchangeable, anionic ion exchanger element
5. central fastener with an anchor, an anchor rod, and an eccentric quick-clamping device
6. reference electrode on the anchor head
7. wetting device
8. power-switching device for anodic regulation
9. measuring system for determining the condition on the ion exchanger element
11. concrete
12. reinforcement
13. combination electrode
14. concrete element (component surface)

WHAT IS CLAIMED IS:

1. A combination electrode for the electrochemical restoration of corrosion-damaged reinforced concrete, characterized in that the electrode comprises the following components:
 - dimensionally stable electrode (1);
 - prefabricated, reusable electrolyte reservoir (2);
 - means for protecting against evaporation (3);
 - prefabricated, exchangeable, anionic ion exchanger element (4);
 - central fastener with anchor, anchor rod, and eccentric quick-clamping device (5);
 - reference electrode (6) on the anchor head;
 - wetting device (7);
 - power-switching device for anodic regulation (8);
 - measuring system (9) for determining the condition on the ion exchanger element; as well as
 - electrical connections for the reference electrode.
2. The combination electrode according to Claim 1, characterized in that the dimensionally stable electrode (1), the means for protecting against evaporation (3), the electrolyte reservoir (2), and the ion exchanger (4) are connected to each other in the form of a sandwich construction.
3. The combination electrode according to Claim 1 or 2, characterized in that it has an area of approximately 0.6 x 0.6 m².
4. The combination electrode according to any one of Claims 1 to 3, characterized in that the dimensionally stable electrode (1) is made of surface-modified titanium or tantalum.
5. The combination electrode according to any one of Claims 1 to 4, characterized in that the electrolyte reservoir (2) is made of a fibrous, mineral material.

6. The combination electrode according to any one of Claims 1 to 5, characterized in that the ion exchanger element (4) includes an anionic ion exchange material that is fixed to a perforated carrier inserted as a layer between the electrolyte reservoir (2) and the electrode (1).
7. The combination electrode according to any one of Claims 1 to 6, characterized in that the measuring system (9), which serves to monitor the consumption status of the ion exchange material, is disposed between the ion exchanger element (4) and the dimensionally stable electrode (1).
8. The combination electrode according to any one of Claims 1 to 7, characterized in that the measuring system (9) for cyclically scanning the consumption status of the ion exchanger material is connected to a computer network via instrument electronics.
9. The combination electrode according to any one of Claims 1 to 8, characterized in that the measuring system (9) comprises a sensor or an auxiliary electrode.
10. The combination electrode according to Claim 9, characterized in that the sensor is a chloride sensor.
11. The combination electrode according to Claim 5, wherein the mineral material is glass mat.
12. A method for controlling an electrode system for a rapid electrochemical restoration of corrosion-damaged reinforced concrete, said electrode system having a plurality of combination electrodes as defined in claim 1, said method characterized in that
 - (a) the combination electrodes are controlled by means of pulse-width-modulated d.c. voltage,
 - (b) wherein a constant voltage of 40 volts is used without limiting the current for the individual combination electrode,

- (c) an unwound shell area of a cover reinforcement is a reference parameter for process dimensioning,
- (d) a chloride sensor is used for signaling and switching off the process when an ion exchanger is saturated,
- (e) a switch-off slope of the pulse-width-modulated d.c. voltage is used for a constant IR correction.

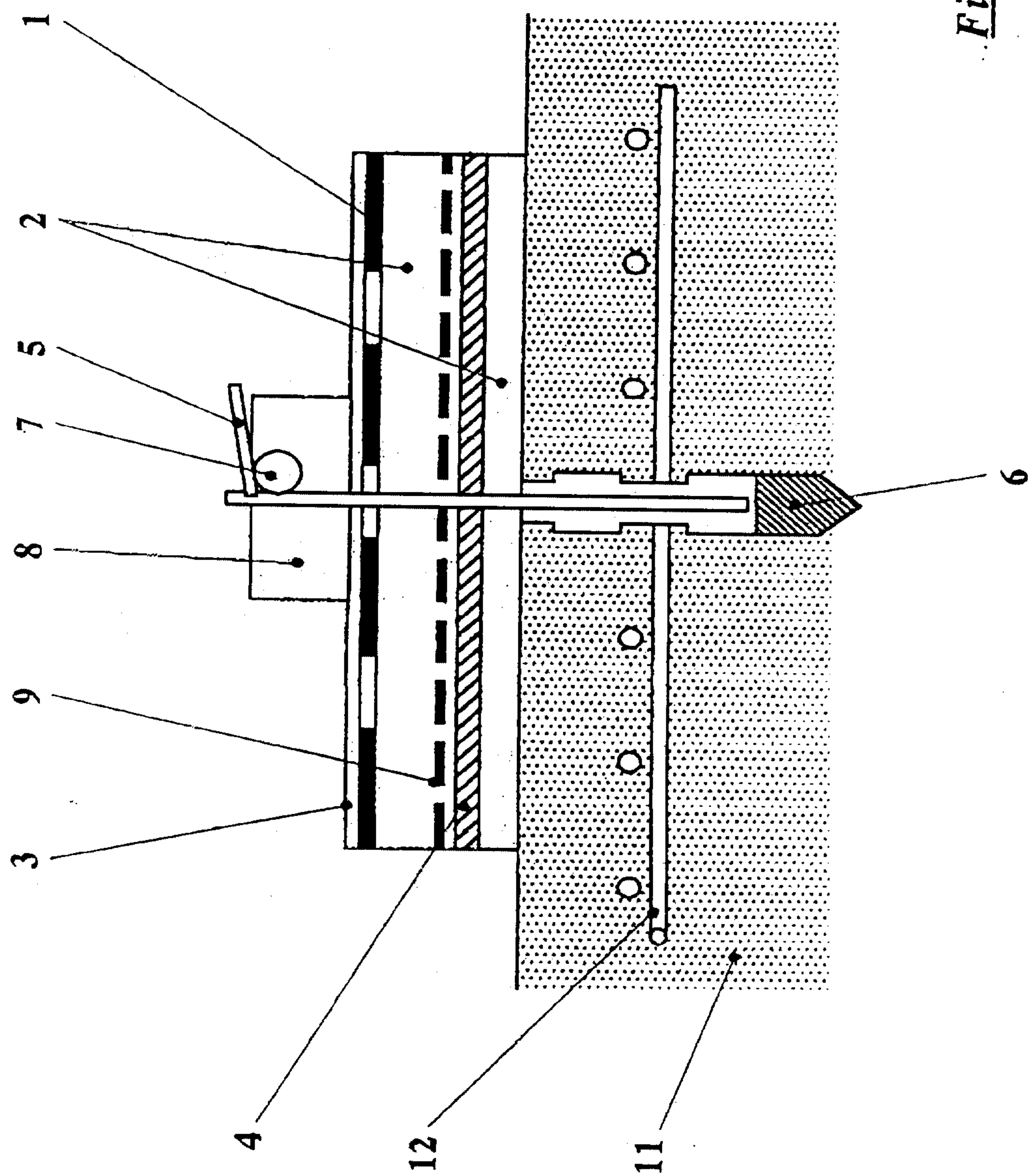
13. The method according to Claim 12, characterized in that the pulse-width-modulated d.c. voltage is applied to each combination electrode that is disposed over a small area, which itself supplies signals required for regulating the pulse-width-modulated d.c. voltage.

14. The method according to Claim 12, characterized in that a frequency and pulse duty ratio of the pulse-width-modulated d.c. voltage are adjusted to control requirements.

15. The method according to Claim 12, characterized in that the unwound shell area of a previously measured cover reinforcement is used as an area of a working cathode.

16. The method according to Claim 12, characterized in that a corresponding measured signal of the chloride sensor that is integrated into the combination electrode leads to the signaling of an occurred saturation condition in the ion exchanger and to a switching-off of the process in the combination electrode.

17. The method according to Claim 12, characterized in that continuous IR correction of the reference potentials of a combination electrode is performed by measuring and evaluating the voltage drop at the switch-off slope of a level adjustment.



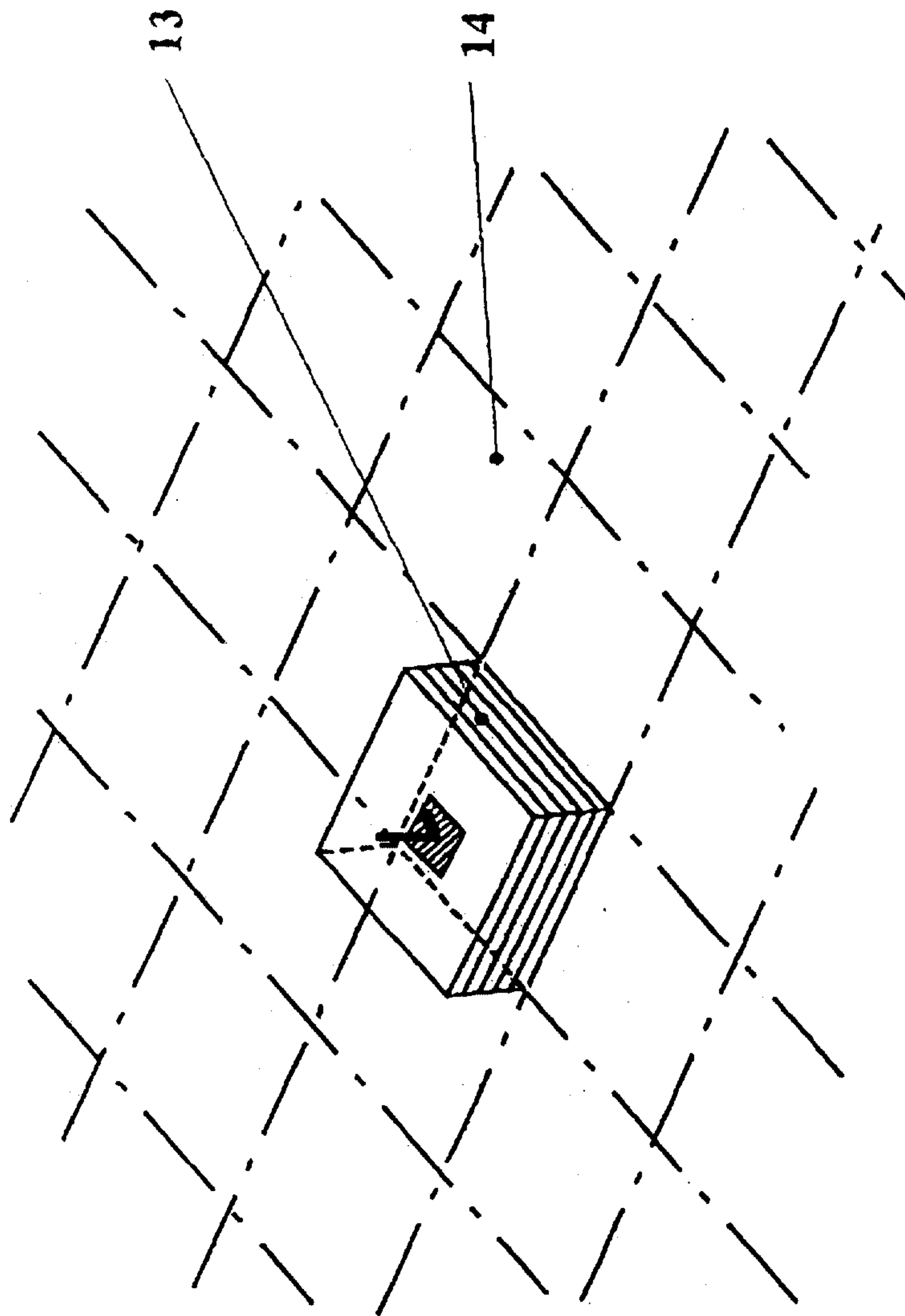


Fig. 2

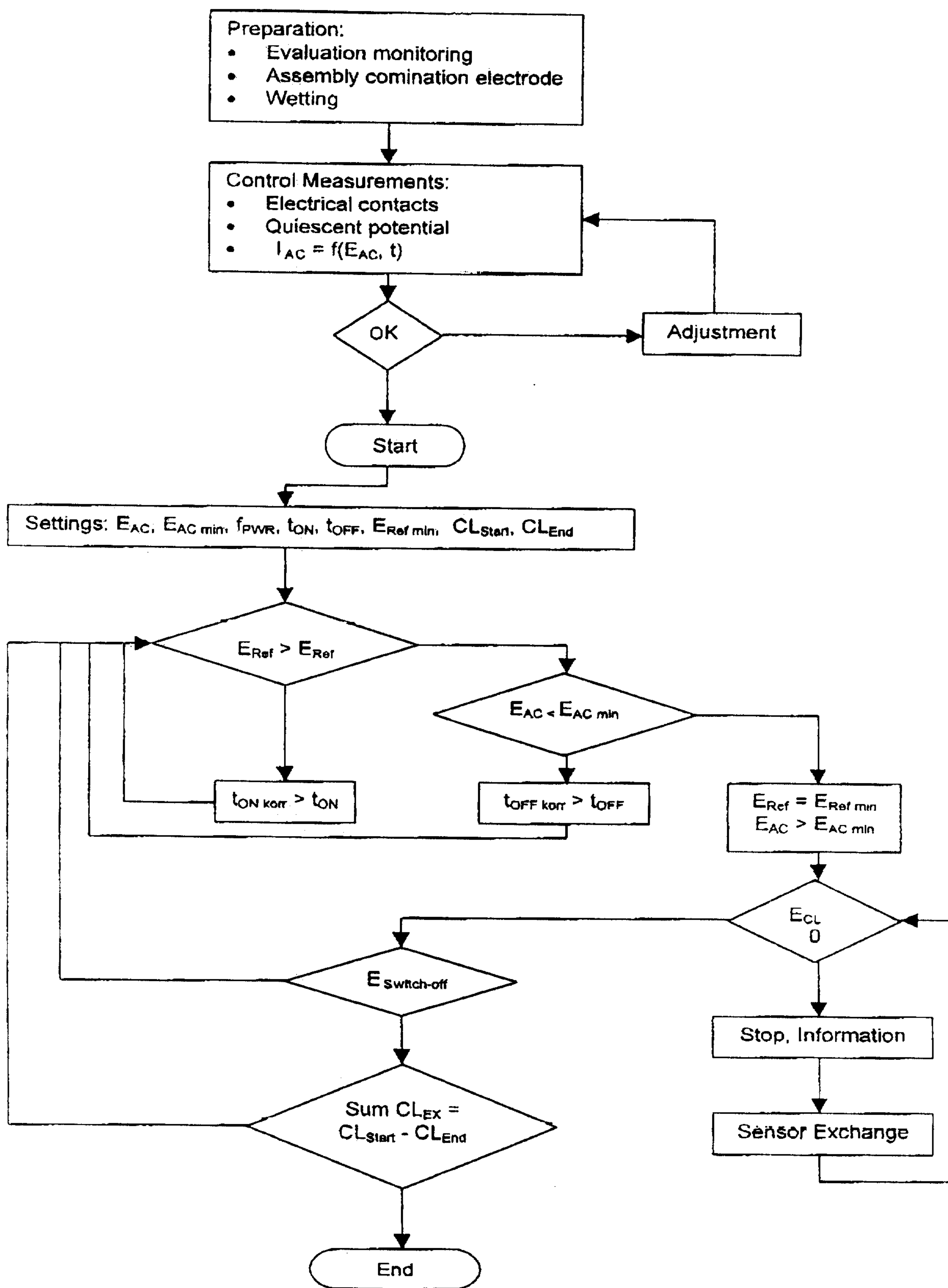


Fig. 3

