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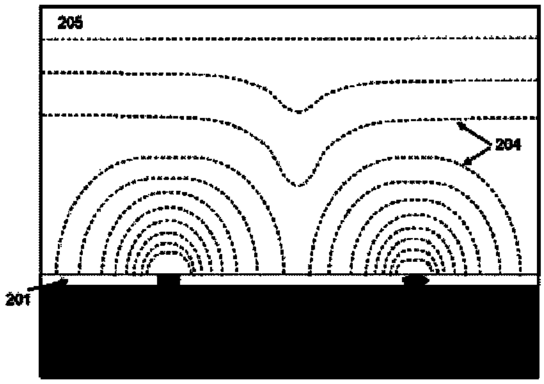
(54) Title **Method for detection of electric fields surrounding a structure in an electrically conducting medium**

(57) Abstract

Method for detection of electric fields surrounding a structure located in an electrically conducting medium, comprising performing a survey by moving at least one electric field gradient sensor along the structure and measuring electric field gradient vectors around the structure, measuring absolute or relative position of the at least one electric field gradient sensor with respect to the structure, and mapping the electric field gradient vectors on a path provided by the movement of the at least one electric field gradient sensor relative to the structure.



INTRODUCTION

The present invention concerns detection of electric fields surrounding a structure in an electrically conducting medium.

BACKGROUND

In order to prevent corrosion damage to valuable metallic structures, e.g. marine structures, submerged installations, seawater containing compartments etc., cathodic protection (CP), e.g. by sacrificial anodes, are installed on the structures, typically in combination with the application of coating. When designing a CP system for a structure, whether it is a new system for the structure, a retrofit modification of an already installed system, or a life extension design of an existing system, full CP should be ensured throughout the entire life of the structure. This is achieved through a proper CP design, where the number of anodes and their positions on the structure are determined. Structures may range from simple geometries, such as pipelines (buried or exposed), to complex geometries such as wellheads, subsea processing equipment and interconnected subsea structures covering large areas.

Typically, numerical modelling is combined with on-site CP inspection to ensure adequate CP and to minimize cost. Numerical CP modelling of structures and pipelines is used to simulate the performance of the CP system throughout the service life. Structures with or without coating can be considered, as well as CP systems based on sacrificial (galvanic) anodes or impressed current, and combinations of these (hybrid CP systems). The quality and reliability of the CP modelling is ensured by utilizing a database with measurement data for the selection of boundary conditions.

In order to verify the condition of the corrosion protection system, the two main methods are potential and field gradient measurements. Potential measurement has in prior art solutions been performed by probes in physical contact with the structures such as in GB2124382A or e.g. as surveys performed by use of a reference electrode suspended from a surface survey vessel and with measurement electrodes towed after the survey surface vessel as in US4,078,510. Other known methods include use of a reference electrode suspended from a survey surface vessel and the measurement electrodes being positioned on a Remotely Operated Vehicles (ROV) connected by wire to the survey surface vessel and the reference electrode. Such inspection technologies are often time consuming and costly. Field gradient measurement has traditionally been performed by electrodes in fixed positions. The data quality from such surveys is also limited, with a low level of detail, especially for buried structures. It is also difficult to inspect entire structures.

SUMMARY OF THE INVENTION

The present invention is conceived to solve or at least alleviate the problems mentioned above.

A first aspect of the present invention provides a method for detection of electric fields surrounding a structure located in an electrically conducting medium, comprising performing a survey by moving at least one electric field gradient sensor along the structure and measuring electric field gradient vectors around the structure, measuring absolute or relative position of the at least one electric field gradient sensor with respect to the structure, mapping the electric field gradient vectors on a path provided by the movement of the at least one electric field gradient sensor relative to the structure.

The method may further comprise moving at least one electric field gradient sensor by using an underwater vehicle.

The method may further comprise measuring a pitch of the at least one electric field gradient sensor relative to the structure.

The method may further comprise acquiring at least one image of the structure while moving the underwater vehicle.

The measurement of position and pitch of the at least one field gradient sensor and acquiring of at least one image of the structure may be obtained while performing the survey.

The movement of the at least one electric field gradient sensor may be pre-programmed based on spatial data of the structure.

The spatial data may be obtained from previous mapping surveys of the structure.

The method may further comprise recording spatial data of the path provided by the movement of the at least one electric field gradient sensor relative to the structure.

The spatial data may be obtained on-site when performing the survey, providing real time information of the electrical fields surrounding the structure resulting in a real time 3D survey of the structure.

The spatial data may obtained from at least one of a sonar sensor, laser measurements, GPS data, inertia based navigation system (INS) or pipe tracking data.

The measuring the electric field gradient vectors around the structure may be performed by using two or more electric field gradient sensors arranged at a fixed angle to each other.

The electric field gradient may be measured using at least one rotating electrode. The at least one electrode may be rotated continuously in one direction, or the direction of the rotation is alternated.

The path may comprises of a series of fixed positions.

The electrically conductive medium may be at least one of seawater, brackish water, fresh water or sediments.

The source of the electric field may be one of a cathodic protection system (CP) of the structure, a corrosion process, stray currents or direct electrical heating (DEH) systems.

The method may further comprise obtaining a model of the structure using a numerical method, taking into account structure geometry, material properties, the source of the electric field, boundary conditions and environmental parameters, establishing a 2D or 3D vector map of the structure based on the mapping of the electric field gradient vectors on the path provided by the movement of the at least one electric field gradient sensor, comparing the vector map with the numerical model characteristics of the structure, and adjusting the boundary conditions of the numerical model until the model converges with the measured 2D or 3D electric field gradient vector map of the structure.

The numerical method may be one of boundary element method (BEM) and finite element method (FEM).

The converged numerical model may provide an assessment the corrosion protection system characteristics of a structure where corrosion control is provided by coating or cathodic protection (CP).

The converged numerical model may provide a mapping of cathodic protection (CP) current flow to structures in sediments.

The converged numerical model may provide an assessment of the influence of at least one of corrosion, stray currents and direct electrical heating (DEH) operation on the structure.

The method may further comprise establishing a 2D or 3D vector map of the structure based on the mapping of the electric field gradient vectors on the path provided by the movement of the at least one electric field gradient sensor, and creating a 2D or 3D vector visualization of the electric field gradient vectors overlaying the structure.

The method may further comprise using the 2D or 3D vector visualization of the electric field gradient vectors overlaying the structure to visually identify and characterize deficiencies in a corrosion protection system.

The method may be used for inspection of structures selected from a list of hull structures, semi-submersibles, floating production storage and offloading (FPSO) units, mooring systems, armoured concrete structures, jackets, flexibles, risers, buried pipelines, exposed pipelines, buried flowlines, exposed flowlines, umbilicals, manifolds, wellheads, X-mas trees, subsea processing equipment, templates, offshore wind turbine foundations and harbour structures.

The method may be used for detection of damages to protective sheathing on subsea electrical cables, for locating submerged objects, or for measurement of electric fields around submarines.

The method may be used for inspection of structures or objects onshore.

The method may further comprise issuing of a report with results presented as text, figures, tables or plots. The report may be issued on any digital medium or on paper.

A second aspect of the invention provides a method for identification of deficiencies in a corrosion protection system and of a structure, comprising identifying positions of deficiencies in the cathodic protection system for the structure by mapping measured electric field gradient vectors on a path obtained from a survey of the structure, wherein the measured electric field gradient vectors have been obtained from the survey by moving at least one electric field gradient sensor along the structure and measuring the electric field gradient vectors around the structure, and wherein the path has been created by the movement of the at least one electric field gradient sensor along the structure.

The method may further comprise obtaining a numerical model of the structure taking into account structure geometry, material properties, source of the electric field, boundary conditions, and environmental parameters, establishing a 2D or 3D vector map of the structure based on the mapping of the electric field gradient vectors on the path provided by the movement of the sensor, comparing the 2D or 3D vector map with the numerical model characteristics of the structure, adjusting boundary conditions of the numerical model until the model converges with the obtained measured 2D or 3D vector map of the structure, and assessing the performance of the corrosion protection system for the structure.

The method may further comprise establishing a 2D or 3D vector map of the structure based on the mapping of the electric field gradient vectors on the path provided by the movement of the at least one electric field gradient sensor, and creating a 2D or 3D vector visualization of the electric field gradient vector overlaying the structure to visually identify deficiencies in the corrosion protection system of the structure.

The method may further comprise issuing of a report with results presented as text, figures, tables or plots. The report may be issued on any digital medium or on paper.

A third aspect of the invention provides a method for tracking a pipe by use of an electric field gradient sensor, comprising measuring an electric field gradient vector in a first position relative to the pipe by using the field gradient sensor, providing a first field gradient vector, measuring the electric field gradient vector in a second position relative to the pipe by using the field gradient sensor, providing a second electric field gradient vector, and establishing the position of the pipe based on an intersection between the first and the second measured electric field gradient vector.

The measurements of the first and the second electric field gradient vector may be performed by use of one electric field gradient sensor performing a sweep between the first and second position.

The measurements of the first and the second electric field gradient vector may be performed by use of at least two electric field gradient sensors arranged at a distance from each other.

The method may further comprise measuring the distance between the electric field gradient sensor and a seabed surface by using a sonar or a laser, and establishing the depth of the pipe by use of the distance to the seabed and the position of the pipe.

The electric field gradient sensor and the sonar or laser may be arranged on an underwater vehicle.

A fourth aspect of the invention provides a method for establishing potential profiles of a cathodically protected structure, comprising performing a survey of the structure by moving at least one electric field gradient sensor along the structure and measuring 2D or 3D electric field gradient vectors around the structure, and calculating potential profiles of the cathodically protected structure, thereby assessing the condition of the corrosion protection system of the structure.

The method may further comprise performing the following steps prior to calculating the potential profile, establishing a numerical model of the cathodically protected structure, and integrating the measured electric field gradient vectors of the structure with the model.

The method may further comprise visualizing the calculated potential profiles, identifying deficiencies in the corrosion protection system of the structure.

The deficiencies may be identified as coating damages, areas where coating has been removed, anodes missing or damaged, or prematurely depleted anodes.

The method may further comprise issuing of a report with results presented as text, figures, tables or plots. The report may be issued on any digital medium or on paper.

BRIEF DESCRIPTION OF DRAWINGS

Example embodiments of the invention will now be described with reference to the followings drawings, where:

Fig. 1 shows a schematic view of an exemplary field gradient sensor.

Fig. 2 shows an example of a potential distribution around a pipeline.

Fig. 3 shows an exemplary calculated current profile.

Fig. 4 shows a method for calculation of potential profile.

Fig. 5 shows an alternative method for calculation of potential profile.

Fig. 6 shows an exemplary field gradient sensor configuration.

Fig. 7 shows an exemplary path of a subsea vehicle and the corresponding electric field gradient vectors measured along a pipeline section.

Fig. 8 shows exemplary paths of a subsea vehicle around a structure and the corresponding measured field gradient vectors.

Fig. 9 shows a method of calibrating a CP model based on results from field gradient measurements.

Fig. 10 shows a schematic view of method of pipe tracking using field gradient sensors.

DETAILED DESCRIPTION

The present invention will be described with reference to the drawings.

An electric field gradient (FG) sensor measures an electric field gradient vector and detects electric currents in an electrically conductive medium, such as seawater, brackish and fresh water, and seabed sediments. Electric fields surrounding a structure located in the electrically conducting medium may be detected by performing a survey by moving at least one electric field gradient sensor along the structure and measuring electric field gradient vectors around the structure. The absolute or relative position of the at least one electric field gradient sensor is measured with respect to the structure. Then the electric field gradient vectors are mapped on a path provided by the movement of the at least one electric field gradient sensor relative to the structure. The term ‘path’ as used herein not only comprise a continuous line of positions, but also a series of fixed positions. The at least one electric field gradient sensor may be moved by using an underwater vehicle. In addition to the measurement of the electric field, a pitch of the at least one electric field gradient sensor relative to the structure may be measured. Also, at least one image of the structure may be acquired while moving the underwater vehicle. The measurement of the position, the pitch of the at least one field gradient sensor and the acquiring of at least one image of the structure may be obtained while performing the survey. Exemplary sources of the measured electric field includes, but are not limited to, a cathodic protection system (CP) of a structure, a corrosion process, stray currents or direct electrical heating (DEH) systems.

The FG sensor measures the electric field gradient using at least one rotating electrode. The at least one electrode may be rotated continuously in one direction. Alternatively, the direction of the rotation of the at least one electrode is alternated. Fig 1 shows a side view of an exemplary FG sensor 100. The FG sensor 100 comprises a housing 101 for sensing electronics, a rotating shaft 102, and two electrodes 103, 104 oppositely positioned on a rotating disk 105. The FG sensor 100 may also be provided with means for mechanical protection 106 of the electrodes 103, 104. The FG sensor 100 measures the electrical field gradient vector by continuously measuring the potential difference between the two electrodes 103, 104 rotating around a common axis 102. Electrochemical potential measurements usually suffer from instabilities when measuring at very accurate levels. The exemplary FG sensor neutralizes these instabilities by utilizing the continuous change in the electrode positions. The disk 105 may rotate continuously in one direction by a predetermined rotational speed. Alternatively, the direction of the rotation of the disk 105 may be alternated by a predetermined frequency. This configuration ensures high accuracy of the measured electrical field gradient, ensuring identification of small coating damages on exposed structures, identification of coating damages on buried structures, and accurate measurements of anode current, both for exposed and buried anodes. The FG sensor 100 may be used both in shallow or deep waters (>4000 m depth) and does not require electric contact with the structure.

The FG sensor 100 may be moved along the structures or pipelines to be inspected attached to a subsea vehicle such as a Remotely Operated Vehicle (ROV), an Autonomous Inspection Vehicle (AIV) or an Autonomous Underwater Vehicle (AUV). The FG sensor measures an electrical field gradient $\vec{FG}$.

$$\vec{FG} = grad\,E = \frac{\partial E}{\partial x}\vec{i} + \frac{\partial E}{\partial y}\vec{j} + \frac{\partial E}{\partial z}\vec{k}$$

FG is a vector field; every point has a magnitude and a direction. When the structure geometry and position data are known, electrical currents may be calculated using Ohms law combined with known or assumed conductivity data.

Fig. 2 shows an example of a potential distribution in water 205 around a pipeline 201 with CP provided by sacrificial anode 202, and a coating damage 206. The coating damage constitutes a cathode relative to the anode 202. The potential distribution is indicated by equipotential lines 204.

The potential profile for a cathodically protected structure, such as the pipeline as illustrated in Fig. 2, may be established by performing a survey of the structure by moving the at least one electric field gradient sensor along the structure and measuring a 2D or 3D electric field gradient vectors around the structure, and calculating potential profiles of the cathodically protected structure, thereby assessing the condition of the corrosion protection system of the structure. The term corrosion protection system includes corrosion control provided by coating or cathodic protection (CP). Visualizing the calculated potential profile of the cathodically protected structure allows identifying deficiencies in the corrosion protection system of the structure. The calculated potential profile may be visualized on a computer screen, printed on paper or any other suitable means for visualizing data. Deficiencies that may be identified include, but are not limited to, coating damages, areas where coating has been removed, anodes missing or damaged, or prematurely depleted anodes.

A first method 400 of calculating the potential profile is illustrated in Fig. 4. In step 401 the field gradient measurement data is collected from the FG sensor. The measurement data may be collected directly from a data storage in the FG sensor unit, a data storage in the subsea vehicle connected to the FG sensor, data storage in a survey vessel connected by wire or wireless to the FG sensor, or from a database comprising data obtained from a previous survey of the structure. In step 405, an anode current I_a is calculated from the peak value i_p of the electrical current curve or an integral of the electrical current per unit length of pipe i(x) as illustrated in Fig. 3. In the next step 406, an anode resistance value R_a is estimated. The value of R_a may be estimated from formulas specified in CP design standards such as DNV-RP-B401. However, these formulas do not take into account inhomogeneous conditions (e.g. the presence of the seabed or partial burial of the pipeline) or the fact that R_a changes gradually over time due to consumption of the anode. Hence, R_a is preferably estimated based on a numerical model taking into account the geometry of the structure and the anodes, water depth, burial depth, conductivity of water and seabed sediments and coating of the structure. In step 406, the anodic potential drop ΔE_a is calculated as $I_a \cdot R_a$, not considering cathodic potential drop or potential drop due to the internal electrical resistance of the structural material. In step 407, the closed circuit potential of the anode E_a is determined, either based on actual potential measurements or based on CP standard design values as specified in CP design standards such as DNV-RP-B401. In step 402, a resistance per unit length of pipe R' is estimated based on a numerical model. Then in step 403, the cathodic potential drop is calculated as $\Delta E_c = R' \cdot I' \cdot A_c$, where I' is the current per unit length of pipe determined in step 402 and A_c the surface area per unit length of pipe. Finally, in step 409, a potential E_c of the structure is calculated as $E_a + \Delta E_a + \Delta E_c$.

A second method 500 of calculating the potential profile is illustrated in Fig. 5. In step 501 the field gradient measurement data is collected as discussed in step 401 with reference to Fig. 4. In step 502, a numerical model of the structure is established. The numerical model takes into account the geometry of the structure and the anodes, water depth, burial depth, conductivity of water and seabed sediments, and coating of the structure. In step 503, the closed circuit potential E_a of the anodes is determined as discussed in step 408 with reference to Fig. 4. Then in step 504, the potential of the structure is determined by integrating the numerical model with the measured electric field gradient vectors of the structure.

The measurement of the electric field gradient vectors around the structure may be performed by using two or more electric field gradient sensors arranged at a fixed angle to each other. Fig. 6 shows an exemplary configuration where two FG sensors 601, 602 are placed 90 degrees relative to each other on a survey vehicle to obtain 3D field gradient measurements. This allows for a detailed evaluation of CP systems for complex structures as the 3D measurements allow measuring not only the magnitude of the field gradient in the vertical plane, transversal to the movement of the sensors along the structure being measured, but also the direction and magnitude of the field gradient in the horizontal plane, i.e. the plane along the direction of the movement of the sensors. Alternatively, measurements can be performed with one electric field gradient sensor measuring while performing a sweep over the structure to be inspected.

A 2D or 3D vector map of the structure may be established based on the mapping of the electric field gradient vectors on the path provided by the movement of the at least one electric field gradient sensor and creating a 2D or 3D vector visualization of the electric field gradient vectors overlaying the structure. The 2D or 3D vector visualization of the electric field gradient vectors overlaying the structure may be further used to visually identify and characterize deficiencies in a corrosion protection system (coating and/or cathodic protection). Fig. 7 shows an exemplary path of a subsea vehicle over a pipeline 701 with sacrificial anodes 702, 703 and a cathode (exposed steel) 704 and the corresponding electric field gradient measurements represented by 3D vectors 705. The vectors 705 contains information about the direction and strength of the electric field around the pipeline. The presence of anodic peaks (upward-pointing vectors) over the anodes and a cathodic peak (downward-pointing vectors) over the cathode is clearly seen. Potential distribution on the pipeline 701 is illustrated in greyscale. Fig. 8 shows an exemplary 3D plot of field gradient measurements around a structure, where recorded positioning data is combined with 3D field gradient data. The 3D visualisation of the field gradient vectors around the structure allows a detailed analysis not possible with 2D data: In the case in Fig. 8, the 3D positioning data allows for further characterisation and quantification of deficiencies in the CP system of the structure.

When analysing the electrical field gradient data, the data are correlated with the position of the sensor relative to the structure or pipeline being inspected. The spatial data of the path provided by the movement of the at least one field gradient sensor relative to the structure is recorded. The spatial data may be obtained on-site when performing the survey, providing real time information of the electrical fields surrounding the structure. This may further result in a real time 3D survey of the structure. Spatial data may be obtained from at least one of a sonar sensor, laser measurements, GPS data, inertia based navigation system (INS) or pipe tracking data. When analysing simple subsea elements such as pipelines or flexibles, the location of the FG sensor tool obtained with the positioning system installed on the subsea vehicle, such as INS, profiler and pipe tracker data, is sufficient. However, when analysing more complex structures such as manifolds or jackets, information about the distance between the sensor(s) and the structure should be recorded in order to analyse the measurements. Technologies such as sonar, laser imaging and 3D laser imaging may be used to map the structure and obtain position data. These imaging technologies, alone or in combination, may be combined with positioning technologies such as GPS to improve the quality of the analyses. On-site positioning data and FG sensor data may be analysed to provide real-time information during the survey, resulting in a real-time 3D survey of the structure. In addition, spatial data of the structure may be used upfront to pre-program the movement of the at least one electric field gradient sensor. The spatial data may be obtained from previous mapping surveys of the structure. The pre-programmed movement of the at least one electric field gradient sensor provides a path where an automated vehicle (e.g. AUV, AIV) will perform the field gradient vector measurements. This then allows for automatic reporting of the results obtained with FG sensor installed on automated subsea vehicles.

Accurate positioning data of the electric field gradient sensor(s) relative to a structure has a major impact on the analysis of the field gradient data. Fig. 7 illustrates the influence of the position of the sensor on the field gradient measurements represented by the magnitude (intensity) of the electric field with respect to distance d3, d2, d1 between pipeline and sensor.

To provide realistic predictions of CP systems performance with time, the FG sensor measurement and position data are input to a numerical CP model. The measured electric field gradient data ensures an accurate calibration of the CP model, improving the prediction capabilities of the model as will be described with reference to Fig. 9. The first step 901 is to obtaining a model of the structure using a numerical method taking into account structure geometry, material properties, the source of the electric field and environmental parameters. The numerical method includes, but are not limited to, boundary element method (BEM) and finite element method (FEM). In step 902, boundary conditions are obtained, e.g. from a database containing historical data such as polarization curves for anodes and data from different subsea locations. In step 903, the numerical CP model is used to simulate the field gradients $FG_{S,n}$. In step 904, field gradient measurement data from the FG sensor are collected FG_M and a 2D or 3D vector map of the structure is established based on the mapping of the electric field gradient vectors on the path provided by the movement of the at least one electric field gradient sensor. In step 905, the vector map is compared with the numerical model characteristics of the structure, i.e. the simulated field gradients $FG_{S,n}$ are compared with the measured field gradients FG_M. If the difference between FG_S and FG_M is too large, i.e. above a predetermined threshold, the boundary conditions of the numerical model are adjusted in step 902 and new simulated field gradients $FG_{S,n+1}$ calculated in step 903. In step 905, the new simulated field gradients $FG_{S,n+1}$ are compared with the measured field gradients FG_M. This iterative process continues until $FG_{S,n+1}$ converges to FG_M within the predetermined threshold and the process continues to step 906 where the converged numerical CP model is used to assess the condition of the structure’s corrosion protection system (coating and/or cathodic protection (CP)). The converged numerical model may also allow for assessment of cathodic protection (CP) current flow to parts of structures buried in sediments. Further, other converged numerical models may be used to assess the influence of at least one of corrosion, stray currents and direct electrical heating (DEH) operation on the structure.

Finally, 3D positioning data allows for repeated, identical surveys to be performed over time, and facilitate visual detection of changes in the CP system of a structure. Additionally, by integrating the survey data with numerical models, it is possible to visualise the actual potential distribution across the structure and electrical field vectors around the structure as shown in Fig 8.

Pipe tracking

The electric field gradient sensor may be used for tracking of buried pipes or other buried structures. An electric field gradient vector is measured in a first position relative to a pipe by using the field gradient sensor, providing a first field gradient vector. The electric field gradient vector is then measured in a second position relative to the pipe by using the field gradient sensor, providing a second field gradient vector. The position of the pipe is established based on the intersection between the first and the second electric field gradient vector. The distance between the electric field gradient sensor and a seabed surface may be measured by using a sonar or a laser. The actual position and depth of the pipe may thus be established by use of the distance to the seabed and the position of the pipe.

The electric field gradient sensor and the sonar may be arranged on an underwater vehicle, such as e.g. a ROV, an AIV or an AUV. Measurement of the first and second electric field gradients may be performed by use of one electric field gradient sensor performing a sweep between the first and second position, or by use of at least two electric field gradient sensors arranged at a distance from each other.

Fig. 10 shows an example of a configuration with two electric field gradient sensors for pipe tracking. Two FG sensors 1001, 1002 are positioned on a survey vehicle (not shown) with a predetermined distance d1 between them. Both sensors measure field gradient vectors around a pipeline, each vector 1003, 1004 indicating a direction to the pipeline. The position of the pipeline 1005 relative to the centre line d4 between the two sensors 1001, 1002 is found by triangulation from the intersection between the two vectors 1003, 1004. This position is sent as feedback to a ROV operator or to an automated vehicle, to maintain the survey vehicle centred over the pipeline. Further, the survey vehicle may include a sensor such as e.g. a sonar sensor or a laser to detect the distance between the survey vehicle and the seabed d2. It is then possible to calculate the burial depth d3 of the pipeline.

Inspection of structures

The invention may be used to inspect the CP systems for a multitude of offshore structures including, but not limited to, hull structures, semi-submersibles, jackets, flexibles, floating production storage and offloading (FPSO) units, mooring systems, risers, buried pipelines, exposed pipelines, buried flowlines, exposed flowlines, umbilicals, manifolds, wellheads, x-mas trees, subsea processing equipment, templates, protection structures, foundations for offshore wind turbines (e.g. monopiles), wind power substations, power cables, concrete structures, harbour structures and installations, etc. The invention can also be used for detection of damages to protective sheathing on subsea electrical cables. Further the invention can be used for locating submerged objects. Further the invention can be used for measurement of electric fields around submarines. The equipment can also be used for mapping of CP current flow to buried structures, such as wells, piles, and suction anchors. The invention may also be used for inspection of structures or objects onshore.

The outcome of the detection of electric fields surrounding a structure located in an electrically conducting medium, e.g. the identification of deficiencies in a cathodic protection (CP) system of a structure or the establishing of potential profiles of a cathodically protected structure, may be issued in a report with results presented as text, figures, tables or plots. The report may be issued on any digital medium or on paper.

Having described some examples of the use of the invention it will be apparent that other configurations may be envisaged as well. The examples of the invention illustrated above are intended by way of example only and the actual scope of the invention is to be determined from the following claims.

CLAIMS –

1. Method for detection of electric fields surrounding a structure located in an electrically conducting medium, the method comprising:

- performing a survey by moving at least one electric field gradient sensor along the structure and measuring electric field gradient vectors around the structure;
-measuring absolute or relative position of the at least one electric field gradient sensor with respect to the structure; and
- mapping the electric field gradient vectors on a path provided by the movement of the at least one electric field gradient sensor relative to the structure.

2. Method according to claim 1, further comprising moving at least one electric field gradient sensor by using an underwater vehicle.

3. Method according to claim 1, further comprising measuring a pitch of the at least one electric field gradient sensor relative to the structure.

4. Method according to claim 2, further comprising acquiring at least one image of the structure while moving the underwater vehicle.

5. Method according to claims 2 to 4, wherein the measurement of position and pitch of the at least one field gradient sensor and acquiring of at least one image of the structure is obtained while performing the survey.

6. Method according to claim 1, wherein the movement of the at least one electric field gradient sensor is preprogrammed based on spatial data of the structure.

7. Method according to claim 6, wherein the spatial data is obtained from previous mapping surveys of the structure.

8. Method according to claim 1, wherein the method further comprises recording spatial data of the path provided by the movement of the at least one electric field gradient sensor relative to the structure.

9. Method according to claim 8, wherein the spatial data is obtained on-site when performing the survey, providing real time information of the electrical fields surrounding the structure resulting in a real time 3D survey of the structure.

10. Method according to claim 8, wherein the spatial data is obtained from at least one of a sonar sensor, laser measurements, GPS data, inertia based navigation system (INS) or pipe tracking data.

11. Method according to claim 1, wherein measuring the electric field gradient vectors around the structure is performed by using two or more electric field gradient sensors arranged at a fixed angle to each other.

12. Method according to claim 1, wherein the electric field gradient is measured using at least one rotating electrode.

13. Method according to claim 12, wherein the at least one electrode is rotated continuously in one direction, or the direction of the rotation is alternated.

14. Method according to claim 1, wherein the path comprises of a series of fixed positions.

15. Method according to claim 1, wherein the electrically conductive medium is at least one of seawater, brackish water, fresh water or sediments.

16. Method according to claim 1, wherein the source of the electric field is one of a cathodic protection system (CP) of the structure, a corrosion process, stray currents or direct electrical heating (DEH) systems.

17. Method according to claim 1, further comprising
-obtaining a model of the structure using a numerical method, taking into account structure geometry, material properties, the source of the electric field, boundary conditions and environmental parameters;
- establishing a 2D or 3D vector map of the structure based on the mapping of the electric field gradient vectors on the path provided by the movement of the at least one electric field gradient sensor;
- comparing the vector map with the numerical model characteristics of the structure, and
- adjusting the boundary conditions of the numerical model until the model converges with the measured 2D or 3D electric field gradient vector map of the structure.

18. Method according to claim 17, wherein the numerical method is one of boundary element method (BEM) and finite element method (FEM).

19. Method according to claim 17, wherein the converged numerical model provides an assessment the corrosion protection system characteristics of a structure where corrosion control is provided by coating or cathodic protection (CP).

20. Method according to claim 17, wherein the converged numerical model provides a mapping of cathodic protection (CP) current flow to structures in sediments.

21. Method according to claim 17, wherein the converged numerical model provides an assessment of the influence of at least one of corrosion, stray currents and direct electrical heating (DEH) operation on the structure.

22. Method according to claim 1, further comprising
- establishing a 2D or 3D vector map of the structure based on the mapping of the electric field gradient vectors on the path provided by the movement of the at least one electric field gradient sensor; and

- creating a 2D or 3D vector visualization of the electric field gradient vectors overlaying the structure.

23. Method according to claim 22, further comprising using the 2D or 3D vector visualization of the electric field gradient vectors overlaying the structure to visually identify and characterize deficiencies in a corrosion protection system.

24. Use of the method according to claim 1 for inspection of structures selected from a list of hull structures, semi-submersibles, floating production storage and offloading (FPSO) units, mooring systems, armoured concrete structures, jackets, flexibles, risers, buried pipelines, exposed pipelines, buried flowlines, exposed flowlines, umbilicals, manifolds, wellheads, X-mas trees, subsea processing equipment, templates, offshore wind turbine foundations and harbour structures.

25. Use of the method according to claim 1 for detection of damages to protective sheathing on subsea electrical cables, for locating submerged objects, or for measurement of electric fields around submarines.

26. Use of the method according to claim 1 for inspection of structures or objects onshore.

27. Method for identification of deficiencies in a corrosion protection system and of a structure, the method comprising:
identifying positions of deficiencies in the cathodic protection system for the structure by mapping measured electric field gradient vectors on a path obtained from a survey of the structure, wherein the measured electric field gradient vectors have been obtained from the survey by moving at least one electric field gradient sensor along the structure and measuring the electric field gradient vectors around the structure, and wherein the path has been created by the movement of the at least one electric field gradient sensor along the structure.

28. Method according to claim 27, further comprising
- obtaining a numerical model of the structure taking into account structure geometry, material properties, source of the electric field, boundary conditions, and environmental parameters;
- establishing a 2D or 3D vector map of the structure based on the mapping of the electric field gradient vectors on the path provided by the movement of the sensor;
- comparing the 2D or 3D vector map with the numerical model characteristics of the structure;
- adjusting boundary conditions of the numerical model until the model converges with the obtained measured 2D or 3D vector map of the structure; and
- assessing the performance of the corrosion protection system for the structure.

29. Method according to claim 27, further comprising
- establishing a 2D or 3D vector map of the structure based on the mapping of the electric field gradient vectors on the path provided by the movement of the at least one electric field gradient sensor; and
- creating a 2D or 3D vector visualization of the electric field gradient vector overlaying the structure to visually identify deficiencies in the corrosion protection system of the structure.

30. Method for tracking a pipe by use of an electric field gradient sensor, the method comprising:
- measuring an electric field gradient vector in a first position relative to the pipe by using the field gradient sensor, providing a first field gradient vector;
- measuring the electric field gradient vector in a second position relative to the pipe by using the field gradient sensor, providing a second electric field gradient vector; and
- establishing the position of the pipe based on an intersection between the first and the second measured electric field gradient vector.

31. Method according to claim 30, wherein the measurements of the first and the second electric field gradient vector are performed by use of one electric field gradient sensor performing a sweep between the first and second position.

32. Method according to claim 30, wherein the measurements of the first and the second electric field gradient vector are performed by use of at least two electric field gradient sensors arranged at a distance from each other.

33. Method according to claim 30, further comprising
- measuring the distance between the electric field gradient sensor and a seabed surface by using a sonar or a laser; and
- establishing the depth of the pipe by use of the distance to the seabed and the position of the pipe.

34. Method according to claim 33, wherein the electric field gradient sensor and the sonar or laser are arranged on an underwater vehicle.

35. Method for establishing potential profiles of a cathodically protected structure, the method comprising:
- performing a survey of the structure by moving at least one electric field gradient sensor along the structure and measuring 2D or 3D electric field gradient vectors around the structure; and
- calculating potential profiles of the cathodically protected structure, thereby assessing the condition of the corrosion protection system of the structure.

36. Method according to claim 35, wherein the following steps are performed prior to calculating the potential profile:
- establishing a numerical model of the cathodically protected structure;
- integrating the measured electric field gradient vectors of the structure with the model.

37. Method according to claim 35, the method further comprising visualizing the calculated potential profiles, identifying deficiencies in the corrosion protection system of the structure.

38. Method according to claim 35, wherein deficiencies may be identified as coating damages, areas where coating has been removed, anodes missing or damaged, or prematurely depleted anodes.

39. Method according to claim 1, 27 or 35, further comprising issuing of a report with results presented as text, figures, tables or plots.

40. Method according to claim 39, wherein the report is issued on any digital medium or on paper.

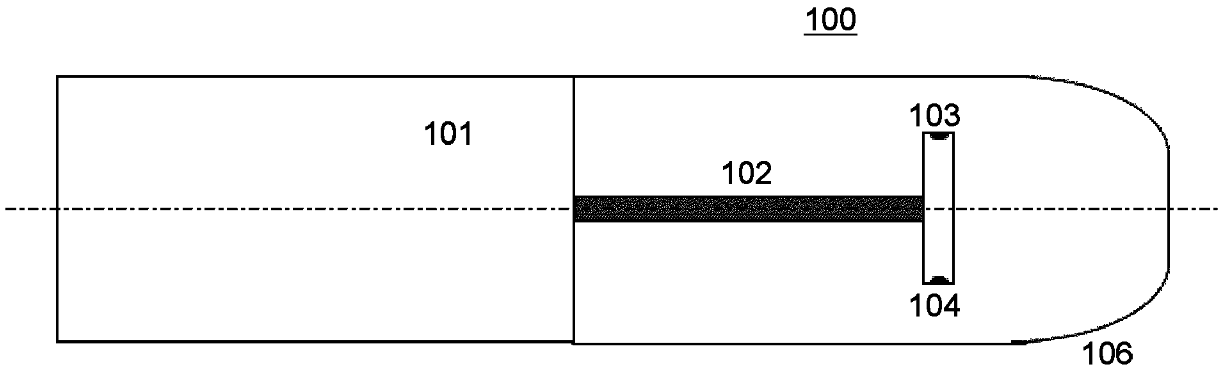


Fig. 1

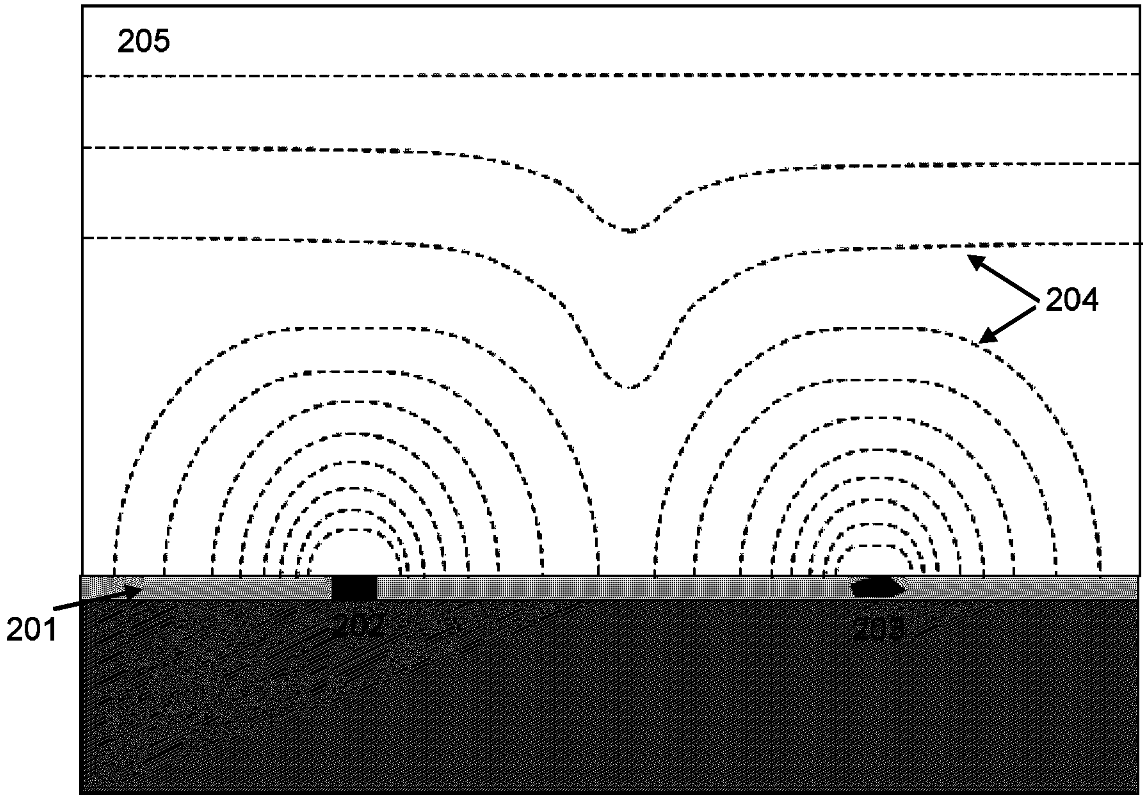


Fig. 2

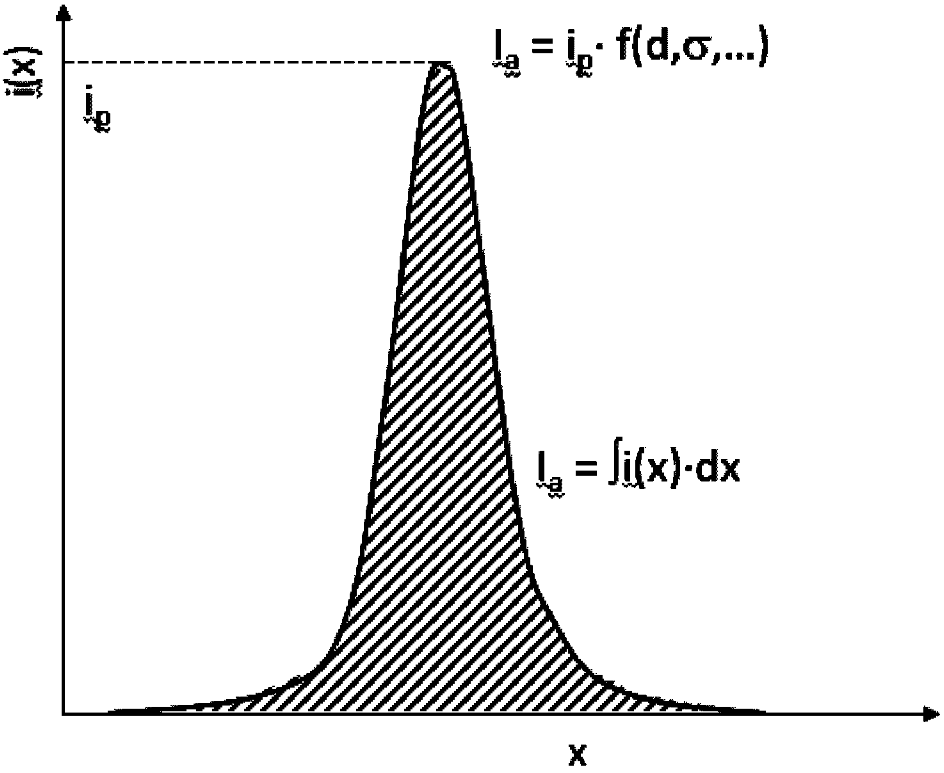

$i(x)$
i_p
$I_a = i_p \cdot f(d,\sigma,\ldots)$
$I_a = \int i(x) \cdot dx$
x

Fig. 3

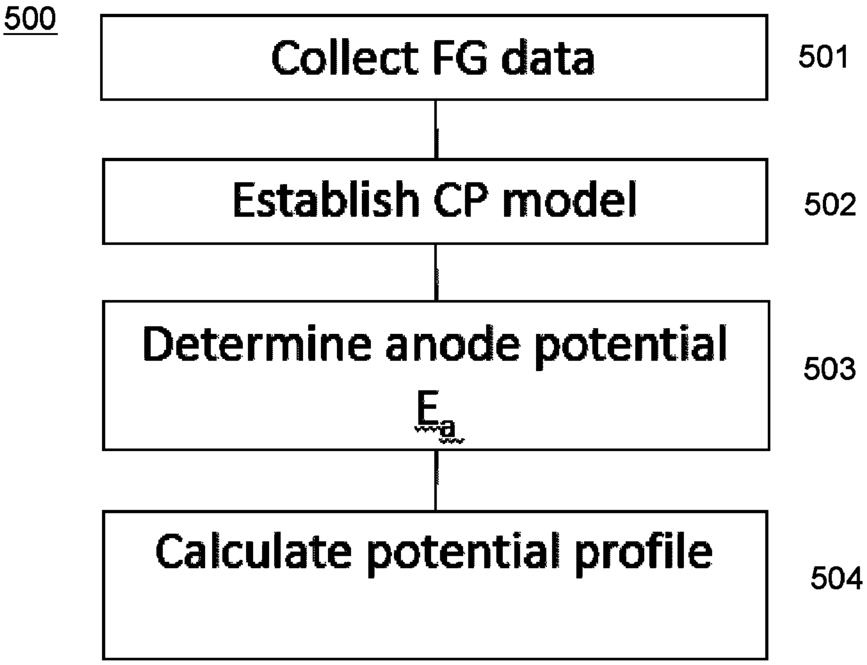

500
Collect FG data
501
Establish CP model
502
Determine anode potential E_a
503
Calculate potential profile
504

Fig. 5

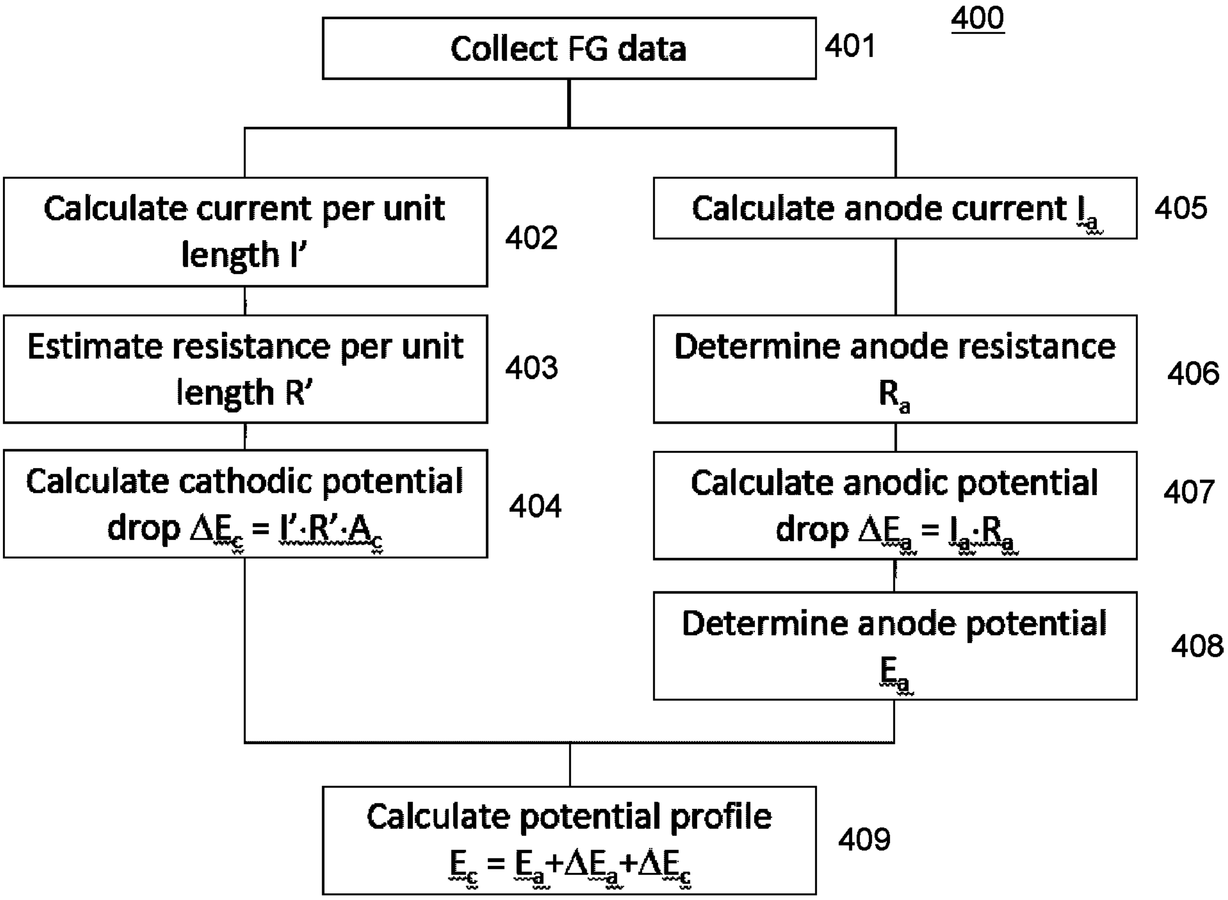

400
Collect FG data
401
Calculate current per unit length I'
402
Estimate resistance per unit length R'
403
Calculate cathodic potential drop $\Delta E_c = I' \cdot R' \cdot A_c$
404
Calculate anode current I_a
405
Determine anode resistance R_a
406
Calculate anodic potential drop $\Delta E_a = I_a \cdot R_a$
407
Determine anode potential E_a
408
Calculate potential profile $E_c = E_a + \Delta E_a + \Delta E_c$
409

Fig. 4

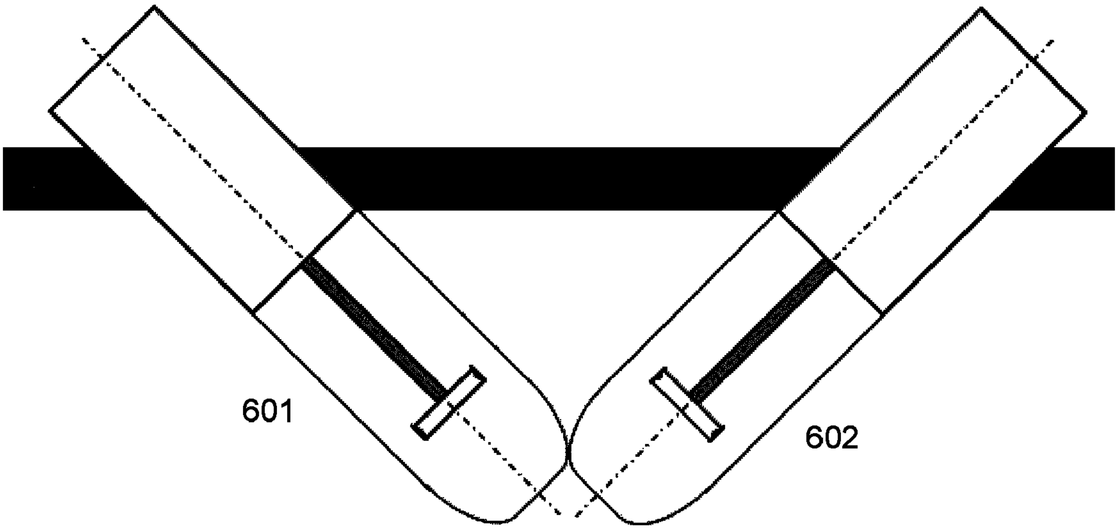

601
602

Fig. 6

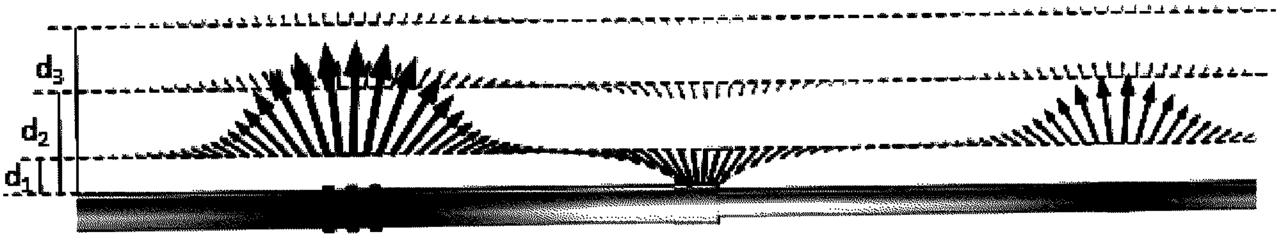


Fig. 7

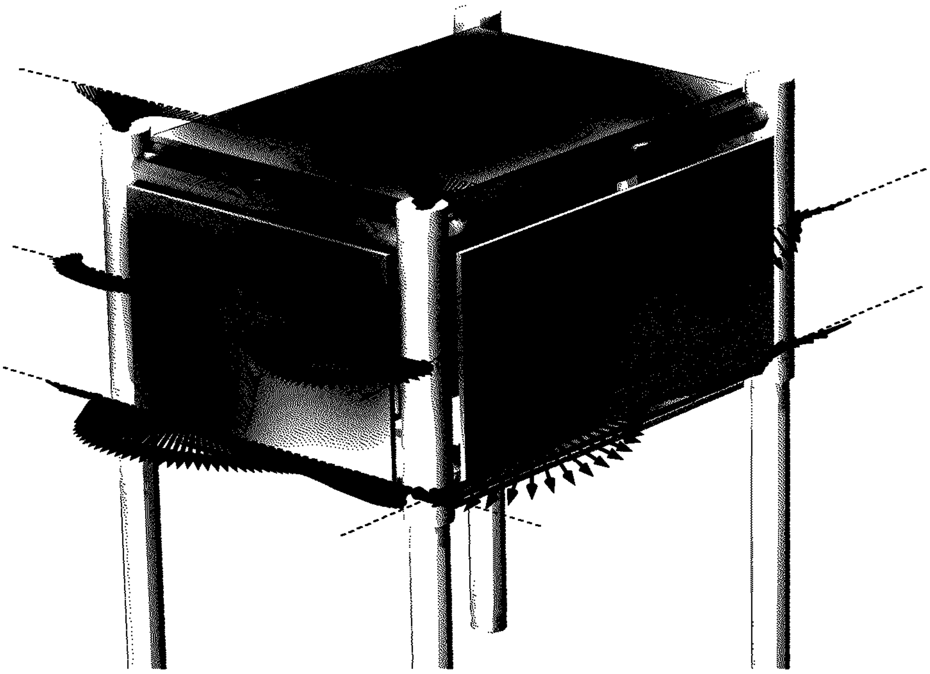


Fig. 8

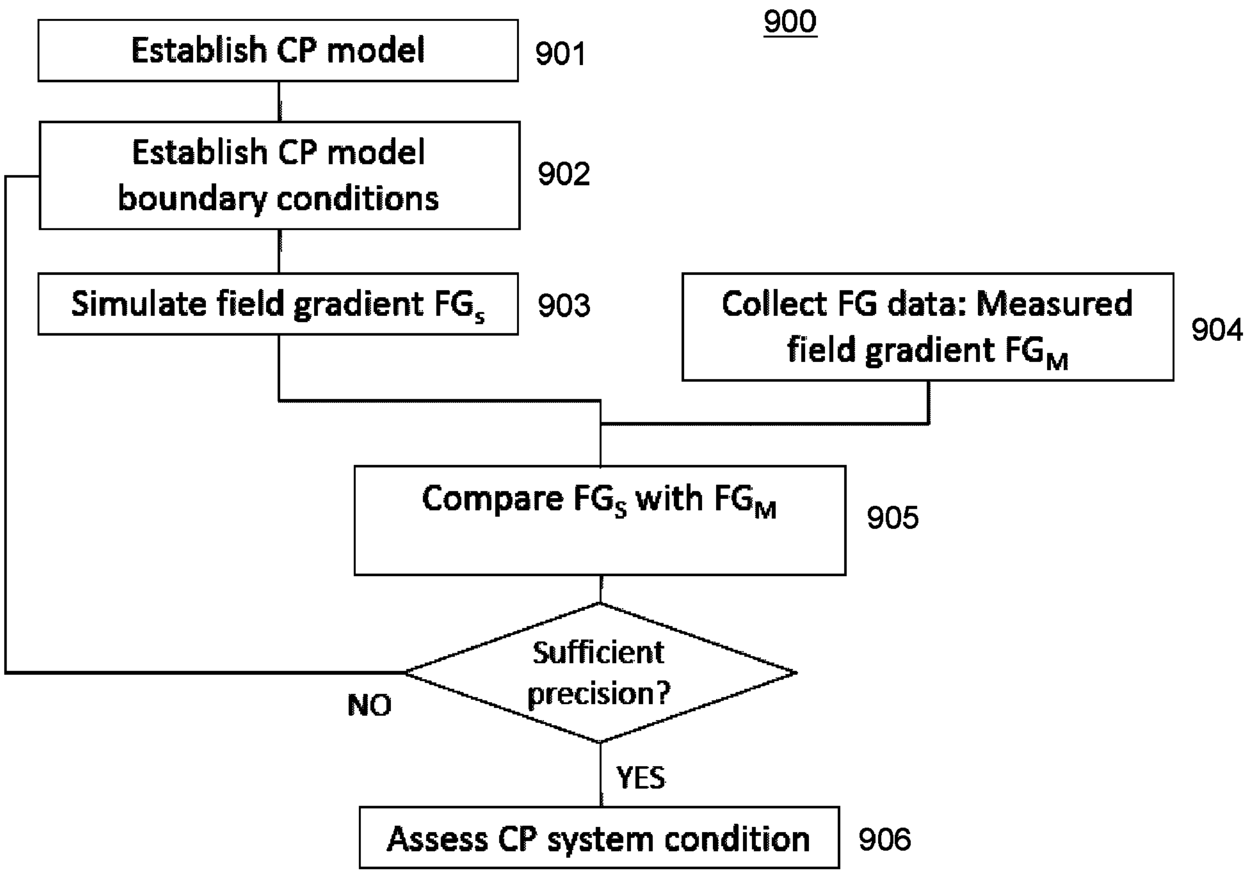

900
Establish CP model
901
Establish CP model boundary conditions
902
Simulate field gradient FG$_S$
903
Collect FG data: Measured field gradient FG$_M$
904
Compare FG$_S$ with FG$_M$
905
Sufficient precision?
NO
YES
Assess CP system condition
906

Fig. 9

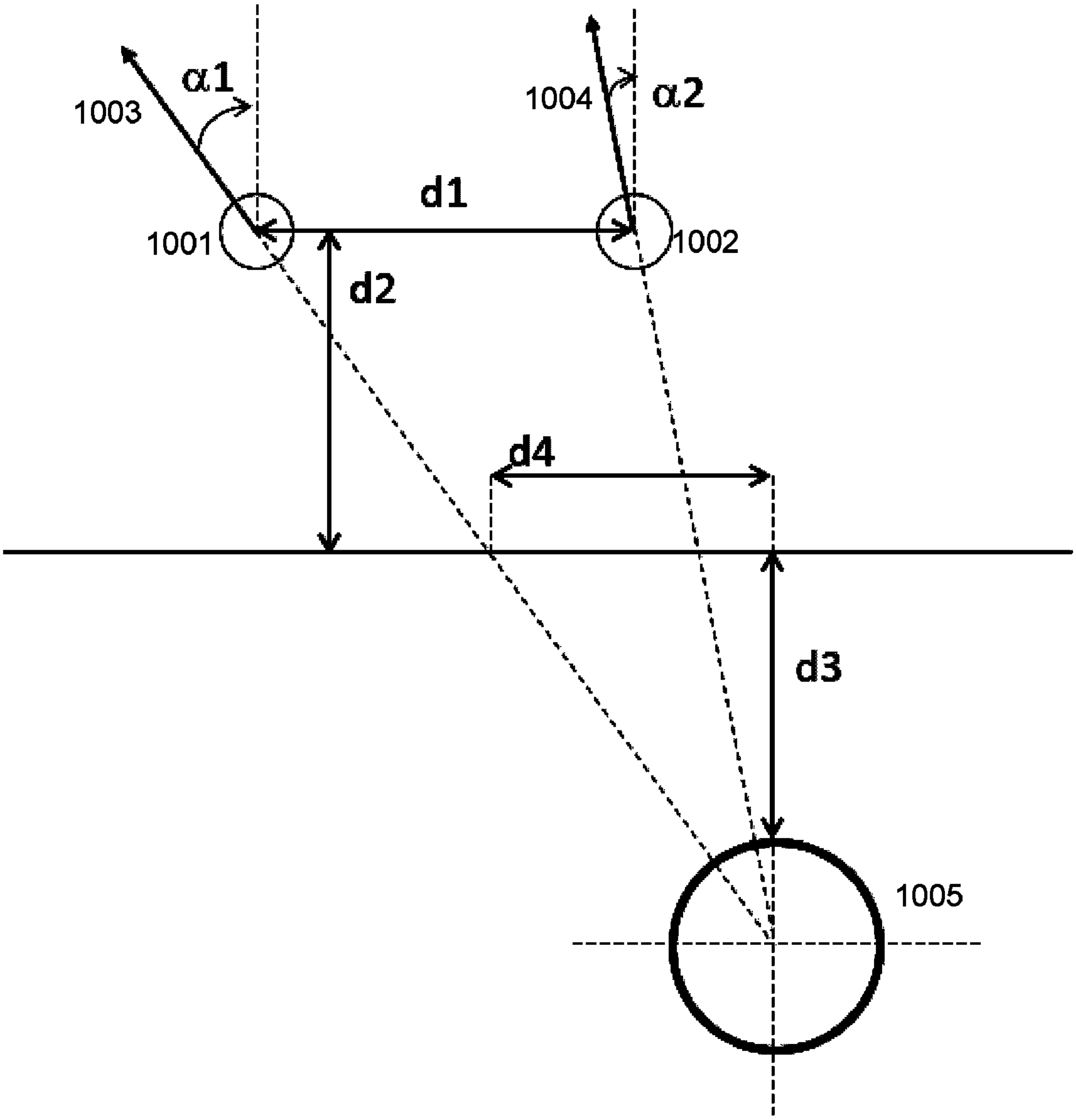


Fig. 10