Title: DIAGNOSTIC METHOD AND APPARATUS FOR ASSESSING THE INSULATION CONDITION OF ELECTRICAL EQUIPMENT INSULATED WITH OIL.

Abstract: A diagnostic method and apparatus for assessing the insulation condition of electrical equipment (3) insulated with oil (2). The method comprises the following steps: measuring the concentration of at least one gas dissolved in the insulating oil (2) of the electrical equipment (3); deriving at least one concentration parameter correlated with the gas concentration measured in a predetermined acquisition time interval; measuring electrical pulses relating to partial electrical discharges which occur in the electrical equipment (3) and which generate said pulses; deriving at least one discharge parameter correlated with the partial discharges measured substantially concurrently with the predetermined acquisition time interval; deriving a diagnostic indication about the insulation condition of the electrical equipment (3) as a function of the derived values of the concentration and discharge parameters.
Description

Diagnostic method and apparatus for assessing the insulation condition of electrical equipment insulated with oil

Technical Field

This invention relates to a diagnostic method and apparatus for assessing the insulation condition of electrical equipment insulated with oil.

More specifically, the invention addresses the field of diagnostic assessment of electrical transformers insulated with oil. In effect, in the field of medium- or high-voltage transformers, oil is frequently used to insulate the transformers.

Background Art

Diagnostic apparatuses for assessing the insulation condition of transformers (or other medium- or high-voltage equipment) insulated with oil have been in use for some time. These apparatuses are based on a technique known as DGA (dissolved gas analysis), for estimating the concentration of gases dissolved in the oil.

DGA is based on measuring the concentration of predetermined types of gases dissolved in the insulation oil in order to derive a diagnostic indication about the insulation condition of the transformer, that is to say, to derive an indication about the source which generates gas in the oil.

More specifically, DGA is used to analyse the concentration of a plurality of gases, including hydrogen, methane, ethane, ethylene, acetylene, carbon monoxide and carbon dioxide.

The umbrella term DGA encompasses several prior art techniques, such as, for example, the Duval triangle method or the techniques based on IEC 60599.

The use of different prior art DGA methods for diagnosing the insulation condition of a transformer starting from the same measured concentration values of gases in the oil often give conflicting diagnostic indications, depending on the specific techniques used. In effect, the techniques often conflict (in terms of criteria for interpreting the data collected for the purpose of identifying the source of the gases detected in the oil).

Thus, a first disadvantage of known diagnostic apparatuses and DGA
diagnostic methods is that they often lead to relatively unreliable indications.

In light of this, it should be noted that the reliability of diagnostic indications for transformers, and more generally, for any electrical equipment, is of crucial importance because technical personnel use these indications to programme maintenance schedules and/or for prompt action to restore optimum insulation conditions of the electrical equipment diagnosed.

A second disadvantage of prior art diagnostic apparatuses based on DGA is connected with the need to identify the sources of the gases dissolved in the oil and to distinguish between the different possible sources in a reliable manner.

As a matter of fact, with the prior art DGA techniques, only a very small number of source types can be identified easily and reliably.

In effect, for identifying many types of sources, the prior art techniques involve detecting types of gases present in very small concentrations. That means these techniques are less reliable, making the gas detection systems based on them more complicated and expensive.

Thus, DGA based diagnostic apparatuses can provide diagnostic indications which can be used to identify only a few sources (causes of degradation) that lead to the formation of gases in a transformer.

Moreover, it should be noted that diagnostic apparatuses based on more advanced DGA techniques involve estimating the concentration of the gas in the oil to be used in subsequent DGA as a function of the value measured inside a measuring chamber separated from the oil container by a membrane permeable to the gas.

The measuring chamber receives through the membrane a part of the gas present in the oil.

Diagnostic apparatuses of this kind are equipped with one or more sensors inside the measuring chamber to measure the concentration of the gas in the measuring chamber itself.

An erroneous estimate of the concentration of a gas dissolved in the oil nullifies the result of subsequent DGA, which consequently provides an incorrect diagnostic indication or, in the worst of cases, does not detect a possible source of degradation in the insulation of the electrical equipment.

This poses a problem of correctly estimating the gas concentration in the oil as a function of the amount of gas measured in the measuring chamber. In effect, it takes a relatively long time for the gas to pass from the oil to the measuring chamber (transient of permeation through the membrane) and this leads to errors estimating the concentration.
Thus, another disadvantage of these diagnostic apparatuses is that they are not robust and are subject to gross errors, since there is a real risk of the estimated gas concentration (used in the known diagnostic methods) being wrong (especially during the transients following the formation of the gas in the oil).

It should be noted that the gas present in the oil is produced (usually) by electrical discharges, also known as partial discharges, which occur in the insulation oil or in other parts of the insulation of the electrical equipment.

Partial discharge is a well-known phenomenon in electrical equipment subjected to medium or high voltages.

A partial discharge is an electric discharge limited to a portion of the insulation of an electrical system and does not therefore cause immediate failure of the system but, more generally, causes its gradual degradation.

By their very nature, therefore, partial discharges are substantially limited in extent to a defect in the insulating system.

It should be noted that partial discharge signals are measured and analysed for diagnostic purposes in the case of electrical equipment with solid or gaseous insulation.

In the case of electrical equipment insulated with oil, however, partial discharge analysis (PDA) methods are not used.

In effect, oil insulation is self-restorative, which means that the defects (partial discharge sources) typical of oil insulators are subject to change and even disappear over time.

To this must be added the fact that partial discharges measured on transformers insulated with oil are significantly affected by noise and do not allow use of interpretation methods normally used on equipment with solid insulators.

Aim of the Invention

This invention has for an aim to provide a diagnostic method and apparatus for assessing the insulation condition of electrical equipment insulated with oil and which overcome the above mentioned disadvantages of the prior art.

In particular, the invention has for an aim to provide a diagnostic method and apparatus for assessing the insulation condition of electrical equipment insulated with oil and which can provide reliable and accurate information about the insulation condition of the electrical equipment itself.

Another aim of the invention is to provide a diagnostic method and apparatus for assessing the insulation condition of a transformer insulated with oil and which can identify in a simple and reliable manner a large number of defects
in the insulation of the transformer itself.

These aims are fully achieved by the method and apparatus according to the invention as characterized in the appended claims.

More specifically, the method of this invention comprises the following steps:
- measuring the concentration of a gas dissolved in the insulating oil of the electrical equipment;
- deriving at least one concentration parameter correlated with the gas concentration measured in a predetermined acquisition time interval.

The method is characterized in that it further comprises the following steps:
- measuring electrical pulses relating to partial electrical discharges which occur in the electrical equipment and which generate said pulses;
- deriving at least one discharge parameter correlated with the partial discharges measured substantially concurrently with the predetermined acquisition time interval;
- deriving a diagnostic indication about the insulation condition of the electrical equipment as a function of the derived values of the concentration and discharge parameters.

The apparatus of the invention is equipped with a device for measuring the concentration of a gas dissolved in the insulating oil of the electrical equipment.

The apparatus is characterized in that it comprises, combined together: a module for measuring electrical pulses relating to partial electrical discharges which occur in the electrical equipment and which generate said pulses; a processing unit connected to the device and to the module for measuring the partial discharges and designed to derive at least one concentration parameter correlated with the measured gas concentration and at least one discharge parameter correlated with the partial discharges and to derive a diagnostic indication about the insulation condition of the electrical equipment as a function of the derived values of the concentration parameter and of the derived values of the discharge parameter, in combination.

Preferably, this combination of the (values of the) concentration and discharge parameters is a non-linear combination.

**Brief Description of the Drawings**

These and other features of the invention will become more apparent from the following description of a preferred, non-limiting embodiment of it, with reference to the accompanying drawings, in which:
- Figure 1 schematically illustrates a device according to this invention;
- Figure 2 shows a flow chart representing the method according to this invention.

Detailed Description of the Preferred Embodiments of the Invention

In the drawings, the numeral 11 denotes a diagnostic apparatus for assessing the insulation condition of electrical equipment 3 insulated with oil 2.

Generally speaking, the electrical equipment 3 is any electrical equipment (for medium or high voltages) insulated with oil, such as, for example, a transformer, a cable or a switch.

In particular, however, this invention addresses a diagnostic apparatus for assessing the insulation condition of a transformer insulated with oil.

Therefore, in the description which follows, the equipment 3 is a transformer.

This shall not, however, be construed as a limitation of the scope of this invention as the diagnostic apparatus 11 can be associated with other types of electrical equipment, such as, for example, a cable or any electrical equipment insulated with oil.

The oil 2 of the transformer is held in a container 7, hereinafter referred to as container 7 of the oil 2.

The diagnostic apparatus 11 is equipped with a device 1 for measuring the concentration of gases dissolved in the oil.

In a preferred embodiment, the device 1 comprises a membrane 5, permeable to gas and interposed between the container 7 of the oil 2 and a measuring chamber 4 to allow gases to pass through it from the container 7 of the oil to the measuring chamber 4.

The device 1 also comprises a sensor 6 mounted in the measuring chamber 4, for measuring the concentration of the gases in the measuring chamber 4, and a control unit 8.

The sensor 6 can measure the concentration of one or more predetermined types of gas.

More specifically, the device 1 is configured to measure at least one of the gases listed below:
- carbon monoxide, hereinafter also referred to as CO;
- hydrogen, hereinafter also referred to as H₂.

Preferably, the device 1 is configured to measure both of the gases listed above.
Alternatively, instead of a single sensor 6, the device 1 might comprise a plurality of sensors, each designed to measure the concentration of a predetermined type of gas.

The device 1 comprises a control unit 8 (or a processor or any other processing means) electrically connected to the sensor 6 to receive from the latter a signal corresponding to the value/values of concentration of the predetermined type/types of gas measured in the measuring chamber 4.

The control unit 8 comprises, preferably, but without limiting the scope of the invention, a memorization module (not illustrated) and a processing module (also not illustrated) functionally connected to the memorization module.

The control unit 8 defines processing means 9 configured to derive an estimated value of gas concentration in the oil 2, as a function of a corresponding value of gas concentration measured inside the measuring chamber 4.

Preferably, the device 1 also comprises a timer connected to the control unit 8 and designed to generate a signal which can be used by the processing module of the control unit 8 to generate (and memorize) measuring instants corresponding to the measurements taken by the sensor 6 in succession. The timer is connected to the control unit 8 also to allow a plurality of measurements (of the value of gas concentration in the measuring chamber 4) to be taken in succession at predetermined measuring instants.

The memorization module of the control unit 8 is designed to memorize the gas concentration values acquired by the sensor 6.

The control unit 8 associates a time information item, according to known techniques, with each acquired value of gas concentration in the measuring chamber 4, obtained, for example, by the timer and relating to the acquisition instant at which that gas concentration value is acquired.

For example, for each gas concentration value measured in the measuring chamber 4, the control unit 8 can memorize directly in the memorization module the time information item regarding the instant that value is acquired; and/or can sort the acquired values of gas concentration in the measuring chamber 4 according to a predetermined sequence and use a predetermined sampling step.

Described below is the operation of the device 1 for deriving the concentration of a gas dissolved in electrical insulation oil 2.

Hereinafter, the following notation will be used:

- $t_i$ to denote a time instant;
- $X_i$ to denote the value for the concentration of a predetermined gas inside the measuring chamber 4 measured by the sensor 6 at the time instant $t_i$;
- \( Y_i \) to denote the estimated value of gas concentration in the oil, calculated by the control unit 8;
- \( \tilde{t} \) to denote a predetermined time interval;
- \( \bar{x} \) to denote a predetermined interval of variation of the gas concentration in the measuring chamber 4 preferably in the predetermined time interval \( \tilde{t} \);
- \( K \) to denote the measurements taken (in the measuring time interval, not less than \( \tilde{t} \)).

Express reference will hereinafter be made to the measurement of the concentration of a generic gas type inside the measuring chamber 4.

The method proposed can therefore be used to measure the concentration of any gas (or plurality of gases) inside the measuring chamber 4 and to estimate its concentration in the oil 2 accordingly.

The electronic control unit 8 acquires from the sensor 6, in a predetermined time interval \( T \) (where \( T \) is not less than \( \tilde{t} \)), a plurality of values \((X_1, X_2, \ldots, X_k)\) for the concentration of one predetermined type of gas inside the measuring chamber 4.

Preferably, the predetermined time interval \( \tilde{t} \) is approximately 24 hours.

Preferably, the concentration values \((X_1, X_2, \ldots, X_k)\) measured inside the measuring chamber 4 are acquired at predetermined time intervals.

More specifically, preferably, but without limiting the scope of the invention, the gas concentration values \((X_1, X_2, \ldots, X_k)\) measured inside the measuring chamber 4 are spaced at a constant time interval, that is to say, these concentration values \((X_{1i}, X_{2i}, \ldots, X_{ki})\) are acquired by the control unit 8 preferably with a constant sampling step.

This advantageously simplifies subsequent processing of the measured concentration values by the control unit 8.

The concentration values \((X_{ji}, X_{2j}, \ldots, X_{kj})\) measured inside the measuring chamber 4 are spaced preferably at a time interval of 15-25 minutes, and still more preferably, approximately twenty minutes.

According to the invention, however, the concentration values \((X_{ji}, X_{2j}, \ldots, X_{kj})\) measured inside the measuring chamber 4 might also be spaced at non-constant time intervals, that is to say, these concentration values \((X_{15}, X_{25}, \ldots, X_{k5})\) might be acquired by the control unit 8 with a sampling step that is not constant.

At each acquisition of a concentration value \( X_{ji} \) in the measuring chamber 4, the control unit 8 checks whether \((t_i - t_j) \times \tilde{t} \), that is to say, whether or not the predetermined time interval \( \tilde{t} \) has passed from the time the first sample \( X_1 \) was
acquired, as illustrated in the block A of the schematic diagram of Figure 2.

It should therefore be observed that the acquisition time interval \( T \), equal to \( t_k-t_1 \), is not less than the predetermined time interval \( \overline{T} \).

The first value acquired after the period \( \overline{T} \), \( X_k \), is compared, preferably but without limiting the scope of the invention, with the very first value acquired, \( X_1 \).

Alternatively, the first value acquired after the predetermined time interval \( \overline{T} \) might be compared with one or more of the previously acquired values \( X_{i-1}, \ldots, X_k \).

This comparison is a comparison of the threshold type, that is to say, the difference \( (X_k-X_i) \) is compared with a predetermined interval \( \overline{X} \) of variation of the gas concentration in the measuring chamber 4.

If the difference \( (X_k-X_i) \) is greater than the predetermined interval \( \overline{X} \) of variation of the gas concentration in the measuring chamber 4, the estimated value \( Y_k \) for the gas concentration in the oil corresponding to the value \( X_k \) is derived by means of a non-linear function of the value \( X_k \) and of the gas concentration values \( (X_1, X_2, \ldots, X_{k-i}) \) previously measured in the measuring chamber 4, that is to say, a non-linear function of the \( Y_k = f(X_i, X_2, \ldots, X_k) \) type.

It should be noted that this check is also carried out for any other value \( X_i \) acquired after the first (\( X^A \), as described above.

In effect, exceeding the predetermined interval \( \overline{X} \) of variation of the gas concentration in the measuring chamber 4 indicates that a more or less sudden variation in the gas concentration in the oil 2 of the electrical equipment 3 is in progress and, hence, that a transient of gas transfer through the membrane 5 is in progress.

Under these conditions it is very likely that an equilibrium has not yet been reached between the gas concentration in the oil 2 and the gas concentration inside the measuring chamber 4, on account of the dynamics of the phenomenon by which the gas passes through the membrane 5 from the oil 2 to the measuring chamber 4.

This non-linear function is also used to estimate the gas concentration in the oil for all the concentration values \( (X_i, X_2, \ldots) \) measured after the first (after finding that the difference \( (X_i-X_i) \) is greater than the predetermined value \( \overline{X} \)).

Preferably, the non-linear function (which links a predetermined gas concentration measured in the chamber 4 to the corresponding concentration of the same gas in the oil 2 in the container 7) is the function shown below by way of an example for the gas concentration value \( X_k \) acquired in the measuring chamber 4.
Where:

- $T_{g,P}$ is Ostwald’s solubility coefficient, which is a function of temperature and pressure,
- $\lambda(T_g,P)$ is the complementary error function, and
- $R_d$ and $D_i$ are experimental constants calculated on the basis of the polymer the membrane is made of.

The estimated value of gas concentration in the oil, $Y_k$, is calculated by the control unit 8, and more specifically, by the processing module.

Advantageously, the aforesaid non-linear function takes into account:

- the dynamics of the process of gas diffusion through the membrane 5, this diffusion process being relatively slow;
- the process of absorption and de-absorption of the gas through the membrane 5.

The aforesaid non-linear function therefore takes into account the transient of gas permeation through the membrane 5 in the predetermined time interval $\tau$.

Thus, the device 1 advantageously makes it possible to derive, with a high degree of accuracy, the value of gas concentration in the oil; more specifically, the device 1 makes it possible to obtain a good estimation of the gas concentration in the oil even for relatively slow gas-oil system transients.

Further, advantageously, the device 1 does not require complex calibrations to correlate the value $X_k$ (that is, any measured value $X_j$) of gas concentration inside the measuring chamber 4 with the value of gas concentration in the oil, as was the case with the prior art devices.

This reduces the setting up time of the device 1 and also decreases the risk of underestimating the value of gas concentration in the oil, in particular when the gas-oil system is far from its thermodynamic equilibrium.

Further, if the gases reach the saturation condition inside the measuring chamber 4, they can be discharged at least partly without diminishing the reliability of the gas concentration measurements performed by the device 1.

In effect, even if transients of gas transfer through the membrane 5 are triggered by the discharge of the gases, the device 1 is able to correctly estimate
the value of gas concentration in the oil by means of the non-linear function.

The method for deriving the concentration of a gas dissolved in oil preferably contemplates, when the control unit 8 detects that \((X_k - X_i)\) is less than the predetermined value or interval \(\bar{x}\) (that is, when \(X_j - X_i\) is less than \(\bar{x}\), for each \(i\) between 2 and \(k\)) of variation of the gas concentration in the measuring chamber 4, deriving the estimated value for the gas concentration \(\bar{\alpha}\) the oil corresponding to the value \(X_i\) by means of a simplified linear function for the concentration value \(X_i\), that is to say, by means of a linear function of the \(Y_j = f(X_j)\) type.

In effect, not exceeding the predetermined interval \(\bar{x}\) of variation of the gas concentration in the measuring chamber 4 indicates a situation of small variation of the gas concentration in the oil 2 in the electrical equipment 3, which in turn indicates a condition of substantial equilibrium of the gas-oil system.

Thus, when the predetermined value or interval \(\bar{x}\) of variation of the concentration is not exceeded, the device 1 uses that linear function advantageously to reduce the computational load of the control unit 8 and to simplify the calculation of the estimated value of the gas concentration in the oil.

Shown below is the linear function preferably used to calculate the estimated value \(Y_j\) of gas concentration in the oil from the measured value \(X_j\) of gas concentration in the measuring chamber 4.

\[ Y_i = \lambda(T_g, P) \ast X_i \]

Where:

- \(\lambda(T_g, P)\)'s Ostwald's solubility coefficient.

The method for deriving the concentration of a gas dissolved in oil, illustrated schematically in Figure 2, is preferably implemented with FIFO logic (that is, the first data item in is the first data item out of the block) with reference to the block C.

In effect, the first estimated value \(Y_1\) of gas concentration in the oil calculated by the control unit using the linear or non-linear function corresponds preferably to the first value \(X_1\) of gas concentration acquired in the measuring chamber 4, and so on for the remaining values.

The description set out above thus defines a method for deriving the concentration of a gas dissolved in an electrical insulating oil 2 of electrical equipment, comprising the following steps:

- preparing a membrane 5 permeable to the gas, interposed between a container 7 of the oil 2 and a measuring chamber 4 that receives a part of the gas through the membrane 5;
- measuring the value of gas concentration in the measuring chamber 4;
- deriving an estimated value of the concentration of the gas in the oil 2 as a
  function of the measured value,
  characterized in that
- measuring comprises taking at successive measuring instants a plurality of
  measurements of the values of gas concentration in the measuring chamber 4;
- deriving comprises calculating the estimated value of gas concentration in
  the oil 2, at an instant selected from said measuring instants, according to a non-
  linear function of the values measured at the selected measuring instant and at one
  or more of the measuring instants preceding the one selected.

Preferably, the plurality of measurements at successive measuring instants
are taken in a predetermined measuring time interval within which the
measurements can be ordered sequentially from a first measurement to a last
measurement.

The method preferably comprises, after at least one of the measurements
taken after the first, comparing that measured value with at least one of the values
preceding the plurality of measured values.

The step of deriving the estimated value of the gas concentration in the oil 2
corresponding to that measurement is performed in a mode selected according to
said comparing step from the following alternatives:
- a calculation according to a non-linear function of the values measured at
  the selected measuring instant and at one or more of the measuring instants
  preceding the one selected, or
- a simplified calculation according to a linear function of the value
  measured at said selected measuring instant.

It should be observed that, preferably, the estimated value of gas
concentration in the oil at an instant selected from said measuring instants, is
calculated according to a non-linear function of the values measured at the
selected measuring instant and at all the measuring instants preceding the one
selected.

According to this invention, the diagnostic apparatus 11 further comprises a
measurement module 10 for measuring electric pulses relating to partial electric
discharges (hereinafter also referred to as PD, the abbreviation of the term Partial
Discharges) which occur in the equipment 3 (more specifically, in the transformer
3), and a processing unit 12.

It should be noted that the control unit 8 and the processing unit 12 can be
integrated in a single processing unit; in any case, the control unit 8 and the
processing unit 12 define the processing means 9.

More specifically, but not necessarily, the measurement module 10 for measuring electric pulses is of the electrical type (alternatively, it might be of optical or acoustical type); the measurement module 10 is configured to measure the current pulses that travel a measuring circuit coupled with the electrical system, of the transformer 3.

The processing unit 12 is connected to the device 1 and to the measurement module 10 for measuring the partial discharges. The processing unit 12 (integrated in the control unit 8 or connected to it) is designed to derive at least one concentration parameter correlated with the gas concentration measured in a predetermined acquisition time interval and at least one discharge parameter correlated with the partial discharges measured concurrently with the same acquisition time interval).

In particular, as regards the expression "concurrently" the following should be noted.

The expression "concurrently" is used to mean that the electrical discharges the discharge parameter is correlated with might be measured in the same acquisition time interval in which the gas concentration is measured or immediately before or after that time interval, that is to say that the discharges do not necessarily have to be acquired in the same time interval in which the gas concentrations are acquired, but might also be acquired before or after that time interval, provided always that gas and PD measurement times are sufficiently close to guarantee that the measured data relating to the gas concentrations and PD signals are pertinent to the same sources.

In effect, it should be observed that, generally speaking, a defect in the insulation of the equipment 3, is at once a source of gas and a source of partial electric discharges (often, the discharges themselves, which occur in the oil or paper insulation, generate the gas).

The processing unit 12 comprises an identification module (not illustrated) connectable to a database containing reference values of predetermined indicators relating to a data set consisting at least of the concentration and discharge parameters.

These reference values of predetermined indicators contained in the database are characteristic values of predetermined categories of sources which generate the partial discharges and/or the gas dissolved in the oil.

The identification module is programmed to compare a data set composed of the values of the concentration and discharge parameters, derived by the
processing unit 12, with the data in the database in order to assign that data set to
one or more of those predetermined categories of sources which generate partial
discharges and/or gas dissolved in the oil.

Preferably, the apparatus 11 also comprises display means (not illustrated),
for example a display unit, connected to the processing unit 12 and designed to
display the diagnostic indication regarding the identified sources of partial
discharges and/or gas dissolved in the oil.

The operation of the diagnostic apparatus 11 is described below.

The device 1 measures the concentration of at least one gas dissolved in the
insulating oil of the electrical equipment 3 (in the manner described above).

More specifically, the device 1 measures the concentrations of CO and H₂
in the oil in a predetermined time interval and transmits these concentrations to
the processing unit 12.

The processing unit 12 derives at least one concentration parameter as a
function of the measured concentration of the at least one gas dissolved in the oil.

Preferably, the processing unit 12 derives the following two concentration
parameters:

- the value of CO concentration in the oil;
- and the value of H₂ concentration in the oil.

The measurement module 10 measures the electrical pulses relating to
partial electrical discharges which occur in the oil and which generate the pulses.

More specifically, it is assumed that the transformer is subjected to
alternating voltage; in light of this, it is possible to attribute to each electrical
pulse (partial discharge) measured, the value of a phase parameter, given by the
phase (or the value) of the voltage applied to the transformer (or to the electrical
equipment 3) at the instant in which the pulse is measured.

Preferably for each pulse measured, the processing unit 12 extracts the
value of parameters correlated with the waveform of the pulse.

More specifically, for each of the pulses measured, the processing unit 12
derives the following:

- the value of an amplitude parameter correlated with the amplitude of the
  pulse measured;
- the value of a phase parameter, representing the value of an alternating
  voltage applied to the electrical equipment at the instants of measuring the pulses;
- the value of a first shape parameter W correlated with the frequency
  content of the pulse;
- and the value of a second shape parameter T, correlated with the duration
of the pulse.

It should be noted that, for deriving the above mentioned shape parameters T and W, the processing unit 12 is preferably programmed to operate as follows:
- the first shape parameter W is derived as standard deviation of the partial discharge pulse processed in the frequency domain;
- the second shape parameter T is derived as standard deviation of the partial discharge pulse processed in the time domain.

The processing unit therefore creates a data set comprising, for each of the pulses measured, the value of the aforesaid shape parameters T and W, of the amplitude parameter, correlated with the amplitude of the pulse measured, and the value of the phase parameter, representing the value of an alternating voltage applied to the electrical equipment at the instants of measuring the pulses.

Preferably, the processing unit 12 processes the data set in order to attribute the activity of partial discharges relating to that data set to one or more categories correlated with the nature of the source of the partial discharges, preferably selected from the following categories:
- internal,
- surface,
- corona.

It is specified that the expression "correlated with the nature of the source of the partial discharges" means that the categories represent the distribution of the electric field within the space region (of the defect that generates the partial discharges) where the PD occur; in effect, it should be observed that the partial discharge activity (that is, the dimension, phase and time sequence of the partial discharges that occur in sequence in a reference time interval) is closely correlated with the distribution of the electric field in the region where the discharges occur.

The "internal" category relates to an activity of partial discharges which occur in the air gaps delimited by dielectric surfaces, or dielectric solids and metal electrodes, and which have a significant component of the electric field at right angles to the surfaces (fixed gaps).

The "surface" category relates to an activity of partial discharges involving the surfaces of solid and/or liquid insulating materials and which have a significant component of the electric field tangential to the discharge surfaces.

The "corona" category relates to an activity of partial discharges which occur in air starting from a pointed element.

Preferably, the processing unit 12 compares the data of the set comprising the amplitude and phase parameters of the measured pulses with reference data
contained in a database and relating to reference values adopted by the amplitude and phase parameters for the aforesaid categories of sources which generate partial discharges (that is to say, internal, surface and corona).

It should be observed that the attribution of the measured discharge activity (that is, the attribution of the measured data set) to the internal / surface / corona categories occurs by processing the data relating to the phase and amplitude of the discharges measured; preferably, this processing consists of assessing the phase-amplitude pattern associated with that data set; more specifically, the assessment is performed preferably using a fuzzy inference engine.

The data set comprising the phase and amplitude parameters of the measured pulses assigned to the aforesaid categories of partial discharge sources constitutes a discharge parameter.

Preferably, the processing unit 12 derives the following discharge parameters:

- an indication of presence or absence of partial discharges in the equipment 3 (that is, in the transformer);
- an indication of presence of intermittent partial discharges in the equipment 3 (that is, in the transformer);
- an attribution of the partial discharges measured (that is, data sets relating to a plurality of PD measured) to the internal, surface and corona categories.

Thus, the processing unit 12 defines the identification module which identifies the type of equipment insulation defect that generates the partial discharges and/or the gases dissolved in the oil.

The identification module of the processing unit 12 compares the data set composed of the values of the concentration and discharge parameters with the reference values of predetermined indicators relating to the concentration and discharge parameters contained in the database in order to attribute that data set to one or more of those predetermined categories of sources of partial discharges and/or gas.

That allows the type of source that generates the partial discharges and/or the gas dissolved in the oil to be identified from among one or more predetermined categories of partial discharges and/or gas.

More specifically, reference will be made below to the case where the equipment 3 consists of a transformer.

The diagnostic apparatus 11 is configured to identify the source (or one or more of the sources) which generate partial discharges and/or gas dissolved in the oil in a transformer from among the categories of sources listed below:
- overheating of the transformer;
- electric arcing in a core of the transformer;
- defects in paper insulation of the transformer;
- electrical discharges produced in the oil by a high voltage electrode of the transformer;
- electrical discharges in poorly impregnated zones inside the transformer;
- oil bubbles;
- discharges produced along an outside surface of the transformer insulation.

The processing unit 12 attributes the derived concentration and discharge parameter data set to the category "overheating of the transformer" if the value of CO concentration in the oil is greater than the corresponding reference value, present in the database, and in the absence of partial discharges in the transformer.

The predetermined database reference value for CO concentration takes into account the CO concentration in the oil under optimum working conditions of the transformer, that is to say, when the transformer is not overheated.

Preferably, the predetermined database reference value for CO concentration is 1500 ppm.

More preferably, the predetermined database reference value for CO concentration is 400 ppm.

The processing unit 12 attributes the derived concentration and discharge parameter data set to the category "electric arcing in a core of the transformer" if the value of $\frac{3}{4}$ concentration in the oil is greater than a corresponding first reference value, corresponding to a "high" concentration of H$_2$, and in the absence of partial discharges.

Preferably, the corresponding first reference value for H$_2$ concentration, corresponding to a "high" concentration of H$_2$, is 10000 ppm.

Preferably, that corresponding first reference value relates to a "high" concentration of H$_2$ in the oil.

The processing unit 12 attributes the derived concentration and discharge parameter data set to the category "electrical discharges produced in the oil by a high voltage electrode of the transformer" if the value of H$_2$ concentration in the oil is greater than the corresponding first reference value, corresponding to a "high" concentration of H$_2$, and in the presence of an activity of partial discharges attributed to the corona category.

Preferably, the corresponding first reference value for H$_2$ concentration, corresponding to a "high" concentration is 10000 ppm.
The processing unit 12 can use as further discharge parameters also the T and W shape parameters to attribute the data set to the category "electrical discharges produced in the oil by a high voltage electrode" so as to derive the diagnostic indication with a higher degree of reliability.

In effect, the aforesaid derived T and W shape parameters have, values which are, respectively, greater than a predetermined reference value (T "high") and lower than another predetermined reference value (W "low") when the source of partial discharges and/or gas are electrical discharges produced in the oil by a high-voltage electrode.

Preferably, the predetermined reference value for T is 5mS, while the predetermined reference value for W is 1Mhz.

The aforesaid reference values for T and W (5ms and 1 Mhz) apply when the signals relating to the electric pulses are carried in a passband typical of a capacitive coupler.

The processing unit 12 attributes the derived concentration and discharge parameter data set to the category "defects in paper insulation of the transformer" if the value of ¾ concentration in the oil is greater than a corresponding reference value, relating to a "low" concentration of ¾ in the oil, and in the presence of intermittent partial discharges.

Preferably, the corresponding reference value for H₂ concentration, corresponding to a "low" concentration of H₂, is 200 ppm.

The processing unit 12 attributes the derived concentration and discharge parameter data set to the category "electrical discharges in poorly impregnated zones inside the transformer" if the value of ¾ concentration in the oil is greater than the corresponding reference value, relating to a "high" concentration of ¾, and in the presence of an activity of partial discharges attributed to the internal and/or surface category.

The processing unit 12 can use as further discharge parameters also the T and W shape parameters to attribute the data set to the category "electrical discharges in poorly impregnated zones inside the transformer" so as to derive the diagnostic indication with a higher degree of reliability.

In effect, the aforesaid derived T and W shape parameters have, values which are, respectively, greater than a predetermined reference value and lower than another predetermined reference value when the source of partial discharges and/or gas are electrical discharges in poorly impregnated zones inside the transformer.

Preferably, the predetermined reference value for T is 5mS, while the
predetermined reference value for \( W \) is 1 Mhz.

The aforesaid reference values for \( T \) and \( W \) (5ms and 1 Mhz) apply when the signals relating to the electric pulses are carried in a passband typical of a capacitive coupler.

The processing unit 12 attributes the derived concentration and discharge parameter data set to the category "oil bubbles" in the transformer if the value of \( H_2 \) concentration in the oil is less than the corresponding reference value, relating to a "low" concentration of \( H_2 \) in the oil, and in the presence of an activity of partial discharges attributed to the internal and/or surface category.

Preferably, the reference value for \( H_2 \) concentration, corresponding to a "low" concentration of \( H_2 \), is 200 ppm.

Further, when the processing unit 12 attributes the derived concentration and discharge parameter data set to the category "oil bubbles", the degree of belonging of the data set comprising the discharge parameters to the categories correlated with the nature of the partial discharge source (internal, surface, corona) is highest for the "internal" category.

The processing unit 12 attributes the derived concentration and discharge parameter data set to the category "electrical discharges produced along an outside surface of the transformer insulation" if the value of \( H_2 \) concentration in the oil is less than a first corresponding reference value, relating to a "high" concentration of \( H_2 \) in the oil and greater than a second corresponding reference value, relating to a "low" concentration of \( \frac{3}{4} \) in the oil and in the presence of an activity of partial discharges attributed to the internal and/or surface category.

Preferably, the first reference value for \( H_2 \) concentration, corresponding to a "high" concentration of \( H_2 \), is 10000 ppm, and the second reference value for \( H_2 \) concentration, corresponding to a "low" concentration of \( H_2 \), is 200 ppm.

Further, when the processing unit 12 attributes the derived concentration and discharge parameter data set to the category "electrical discharges produced along an outside surface of the transformer insulation", the degree of belonging of the data set comprising the discharge parameters to the categories correlated with the nature of the partial discharge source (internal, surface, corona) is highest for the "surface" category.

Table 1 below shows the attribution of the sources of partial discharges and/or gas as a function of the values of the concentration parameter/s and of the discharge parameter/s using the diagnostic method and the diagnostic apparatus of this invention.
Table 1

<table>
<thead>
<tr>
<th>DGA</th>
<th>PDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>concentration of H2 greater than a predetermined value (high)</td>
<td>electric arcing in a core</td>
</tr>
<tr>
<td>concentration of H2 between two predetermined values (medium)</td>
<td>electrical discharges from a high voltage electrode</td>
</tr>
<tr>
<td>concentration of H2 less than a predetermined value (low)</td>
<td>discharges along an outside surface of the transformer</td>
</tr>
<tr>
<td>Presence of CO</td>
<td>overheating of the transformer</td>
</tr>
</tbody>
</table>

The processing unit 12 may further comprise a filtering module, that is, a filter, configurable to select only a part of the electrical pulses relating to partial discharges measured in the acquisition time interval so as to derive the discharge parameter only on the selected part of the partial discharges.

For example, the filter allows the processing unit 12 to derive one or more discharge parameters correlated with the partial discharges and excluding electrical discharges due to predetermined types of noise, so as to advantageously derive discharge parameters which are reliable and immune to noise.

The diagnostic apparatus 11 advantageously makes it possible to obtain highly reliable diagnostic indications regarding the insulation state of electrical equipment, in particular a transformer.

In effect, the diagnostic apparatus 11 derives a diagnostic indication about the insulation conditions of electrical equipment by combining DGA with PDA.

Thus, the apparatus 11 proposed is particularly robust against uncertainty of measured data, as regards both DGA and PDA.

In effect, according to the invention, to perform a reliable diagnosis (with an excellent capacity of discernment to distinguish the type of defect) it is sufficient to measure the gases (CO and H₂) with the highest concentrations (and thus particularly easy and reliable to measure) and from there derive indications on the nature of the PD sources.

Compared to DGA based prior art diagnostic apparatuses, this diagnostic apparatus can provide a higher number of diagnostic indications by measuring the concentration in oil of a smaller number of gases, with obvious advantages in terms of costs and operating reliability of the diagnostic apparatus.

Furthermore, unlike the case of prior art DGA solutions, any errors in
estimating the concentration of one or more gases in the oil do not significantly reduce the reliability of the diagnostic indications derived by the apparatus 11; in effect, the diagnostic information is derived using at least one concentration parameter obtained by DGA and at least one discharge parameter obtained by PDA.

Advantageously, therefore, the sensors used in the diagnostic apparatus 11 to measure the concentration of gases in the oil may be less precise and accurate than those of the prior art, DGA based apparatuses, with obvious advantages in terms of costs.

Another advantage of this invention is that it provides a diagnostic apparatus 11 that can identify in a transformer a plurality of sources which generate partial discharges and/or gas dissolved in the oil with a high degree of discernment to distinguish these sources but without complicating the apparatus.

Moreover, the diagnostic apparatus of the invention uses a fuzzy inference engine operating on the concentration and discharge parameter to derive the aforesaid diagnostic indication.

The fuzzy inference engine makes it possible to attribute the data set composed of the values of the concentration and discharge parameters to one or more categories of sources which generate partial discharges and/or gas dissolved in the oil using predetermined rules applied to the concentration and discharge parameter/parameters.

This advantageously allows even more accurate diagnostic indications to be obtained, including an indication about the certainty (or uncertainty) of the indication provided, usually referred to by the term "likelihood".

In other embodiments of the diagnostic apparatus, other diagnostic indications about the insulation conditions of a transformer are derived on the basis of a data set consisting of a combination of one or more concentration parameters and one or more discharge parameters from among those set out above.

In any event, the data set comprising at least one concentration parameter and one discharge parameter must include a combination of concentration and discharge parameters from which at least one of the above mentioned sources of electrical discharges and/or gas must be identifiable.

Moreover, the apparatus 11 can derive further concentration and discharge parameters to improve the reliability of the diagnostic indications derived therefrom compared to those described above.

The description set out above also defines a diagnostic method for assessing
the insulation condition of electrical equipment 3 insulated with oil 2, comprising
the following steps:
- measuring the concentration of at least one gas dissolved in the insulating
  oil 2 in the electrical equipment 3;
- deriving at least one concentration parameter correlated with the gas
  concentration measured in a predetermined acquisition time interval,
- measuring electrical pulses relating to partial electrical discharges which
  occur in the electrical equipment 3 and which generate said pulses;
- deriving at least one discharge parameter correlated with the partial
  discharges measured substantially concurrently with the predetermined acquisition
  time interval;
- deriving a diagnostic indication about the insulation condition of the
  electrical equipment 3 as a function of the derived values of the concentration
  parameter and of the discharge parameter, in combination.

Preferably, in this method, the step of deriving the diagnostic indication
comprises the following steps:
- preparing a database containing reference values of predetermined
  indicators relating to a data set comprising at least said concentration and
  discharge parameters, said reference values being characteristic of predetermined
  categories of sources that generate the partial discharges and/or the gas dissolved
  in the oil;
- comparing a data set composed of derived values of the concentration and
  discharge parameters with the data in the database in order to assign said data set
  to one or more of said source categories, thereby identifying the type of source
  that generates the partial discharges and/or the gas dissolved in the oil.

In another embodiment of the diagnostic method, the step of comparing a
data set composed of derived values of the concentration and discharge
parameters with the data in the database in order to assign said data set to one or
more of said source categories is performed in order to provide a signal regarding
the insulation condition of the electrical equipment 3.

The signal may comprise information regarding the state of the insulation
(for example, a traffic light which is green if the state of the insulation is good or
red if the insulation is not in good condition and the electrical equipment requires
attention) or it may comprise information regarding the operation to be carried out
on the transformer.

Further, in yet another embodiment of the diagnostic method, the step of
deriving a diagnostic indication comprises using a fuzzy inference engine
operating on the at least one concentration parameter and on the at least one discharge parameter in order to derive said diagnostic indication.

It will be understood that the invention described is susceptible of industrial application and may be modified and adapted in several ways without thereby departing from the scope of the inventive concept. Moreover, all the details of the invention may be substituted by technically equivalent elements.
Claims

1. A diagnostic method for assessing the insulation condition of electrical equipment (3) insulated with oil (2), comprising the following steps:
   - measuring the concentration of at least one gas dissolved in the insulating oil (2) in the electrical equipment (3);
   - deriving at least one concentration parameter correlated with the gas concentration measured in a predetermined acquisition time interval, characterized in that it further comprises the following steps:
     - measuring electrical pulses relating to partial electrical discharges which occur in the electrical equipment (3) and which generate said pulses;
     - deriving at least one discharge parameter correlated with the partial discharges measured substantially concurrently with the predetermined acquisition time interval;
   - deriving a diagnostic indication about the insulation condition of the electrical equipment (3) as a function of the derived values of the concentration parameter and of the discharge parameter, in combination.

2. The method according to claim 1, wherein the step of deriving the diagnostic indication comprises the following steps:
   - preparing a database containing reference values of predetermined indicators relating to a data set comprising at least said concentration and discharge parameters, said reference values being characteristic of predetermined categories of sources that generate the partial discharges and/or the gas dissolved in the oil;
   - comparing a data set composed of derived values of the concentration and discharge parameters with the data in the database in order to assign said data set to one or more of said source categories in order to provide a signal regarding the insulation condition of the electrical equipment (3).

3. The method according to claim 1, wherein the step of deriving the diagnostic indication comprises the following steps:
   - preparing a database containing reference values of predetermined indicators relating to a data set comprising at least said concentration and discharge parameters, said reference values being characteristic of predetermined categories of sources that generate the partial discharges and/or the gas dissolved in the oil;
- comparing a data set composed of derived values of the concentration and
discharge parameters with the data in the database in order to assign said data set
to one or more of said source categories, thereby identifying the type of source
that generates the partial discharges and/or the gas dissolved in the oil.

4. The method according to claim 3, wherein the electrical equipment is a
transformer and the predetermined categories of sources that generate the partial
discharges and/or the gas dissolved in the oil comprise one or more of the
categories from the following list:
- overheating of the transformer;
- electric arcing in a core of the transformer;
- defects in paper insulation of the transformer;
- electrical discharges produced in the oil by a high voltage electrode of the
  transformer;
- electrical discharges in poorly impregnated zones inside the transformer;
- oil bubbles;
- discharges produced along an outside surface of the transformer insulation.

5. The method according to claim 4, comprising deriving a concentration of
CO in the oil, constituting said at least one concentration parameter, and an
indication of the presence or absence of partial discharges measured in the
transformer, constituting said at least one discharge parameter, the measured data
set being assigned to the category of overheating of the transformer if the value of
CO concentration in the oil is greater than a corresponding reference value and in
the absence of partial discharges.

6. The method according to claim 4 or 5, comprising deriving a
concentration of \( \text{H}_2 \) in the oil (2), constituting said at least one concentration
parameter, and an indication of the presence or absence of partial discharges
measured in the transformer, constituting said at least one discharge parameter,
the measured data set being assigned to the category of electric arcing in a core of
the transformer if the value of \( \text{H}_2 \) concentration in the oil is greater than a
 corresponding reference value and in the absence of partial discharges.

7. The method according to any of the claims from 4 to 6, comprising
 deriving a concentration of \( \frac{3}{4} \) in the oil (2), constituting said at least one
concentration parameter, and an indication of the presence or absence of partial intermittent discharges measured in the transformer, constituting said at least one discharge parameter, the measured data set being assigned to the category of defects in paper insulation of the transformer if the value of $H_2$ concentration in the oil is greater than a corresponding reference value and in the presence of partial intermittent discharges.

8. The method according to any of the claims from 4 to 7, wherein the step of deriving the discharge parameters comprises:
- generating a data set comprising, for each of the pulses measured, the value of an amplitude parameter, correlated with the amplitude of the pulse measured, and the value of a phase parameter, representing the value of an alternating voltage applied to the electrical equipment at the instants of measuring the pulses, and
- processing the data set in order to assign the activity of partial discharges relating to said data set to one or more categories correlated with the nature of the source of the partial discharges, selected from the following categories: internal, surface and corona,
  the assigned categories of partial discharge sources constituting the at least one discharge parameter.

9. The method according to claim 8, comprising deriving a concentration of $H_2$ in the oil (2), constituting said at least one concentration parameter, the measured data set being assigned to the category of electrical discharges produced in the oil by a high voltage electrode of the transformer if the value of $H_2$ concentration in the oil is greater than a corresponding reference value and in the presence of an activity of partial discharges assigned to the corona category.

10. The method according to claim 8 or 9, comprising deriving a concentration of $H_2$ in the oil (2), constituting said at least one concentration parameter, the measured data set being assigned to the category of electrical discharges in poorly impregnated zones inside the transformer if the value of $H_2$ concentration in the oil is greater than a corresponding reference value and in the presence of an activity of partial discharges assigned to the surface or corona category.

11. The method according to any of the claims from 8 to 10, comprising
deriving a concentration of H₂ in the oil (2), constituting said at least one concentration parameter, the measured data set being assigned to the category of oil bubbles in the transformer if the value of H₂ concentration in the oil is less than a corresponding reference value and in the presence of an activity of partial discharges assigned to the surface or corona category.

12. The method according to any of the claims from 8 to 11, comprising deriving a concentration of H₂ in the oil (2), constituting said at least one concentration parameter, the measured data set being assigned to the category of discharges produced along an outside surface of the transformer insulation if the value of H₂ concentration in the oil is less than a corresponding first reference value and greater than a corresponding second reference value less than the first reference value, and in the presence of an activity of partial discharges assigned to the surface or corona category.

13. The method according to any of the foregoing claims, wherein the step of deriving a diagnostic indication comprises using a fuzzy inference engine operating on the at least one concentration parameter and on the at least discharge parameter in order to derive said diagnostic indication.

14. The method according to any of the foregoing claims, wherein the step of measuring the concentration of a gas dissolved in the insulating oil of the electrical equipment comprises the steps of:
- preparing a membrane (5) permeable to the gas, interposed between a container (7) of the oil (2) and a measuring chamber (4) that receives a part of the gas through the membrane (5);
- taking at successive measuring instants a plurality of measurements of the values of gas concentration in the measuring chamber (4) which is separated from the oil container by the permeable membrane (5);
- deriving a value of gas concentration in the oil (2) at an instant selected from said measuring instants, according to a non-linear function of the values measured at the selected measuring instant and at one or more of the measuring instants preceding the one selected.

15. A diagnostic apparatus (11) for assessing the insulation condition of electrical equipment (3) insulated with oil (2), equipped with a device (1) for measuring at least the concentration of a gas dissolved in the insulating oil (2) of
the electrical equipment (3),
characterized in that the diagnostic apparatus comprises, combined
together:
- a module (10) for measuring electrical pulses relating to partial electrical
discharges which occur in the electrical equipment (3) and which generate said pulses;
- a processing unit (12) connected to the device (1) and to the module (10)
for measuring the partial discharges and designed to derive at least one concentration parameter correlated with the gas concentration and at least one discharge parameter correlated with the partial discharges and to derive a
diagnostic indication about the insulation condition of the electrical equipment (3), as a function of the derived values of the at least one concentration parameter and the at least one discharge parameter, in combination.

16. The apparatus according to claim 15, comprising an identification
module which can be connected to a data base containing reference values of predetermined indicators relating to a data set comprising at least said concentration and discharge parameters, said reference values being characteristic of said predetermined source categories that generate partial discharges and/or the gas dissolved in the oil, said identification module being programmed to compare a data set composed of derived values of the concentration and discharge parameters with the data in the database in order to assign said data set to one or more of said source categories, thereby identifying the type of source that generates the partial discharges and/or the gas dissolved in the oil.

17. The apparatus according to claim 16, wherein the electrical equipment
is a transformer and the identification module is adapted to identify one or more of the categories from the following list of the said predetermined categories of sources that generate the partial discharges and/or the gas dissolved in the oil:
- overheating of the transformer;
- electric arcing in a core of the transformer;
- defects in paper insulation of the transformer;
- electrical discharges produced in the oil by a high voltage electrode of the transformer;
- electrical discharges in poorly impregnated zones inside the transformer;
- oil bubbles;
- discharges produced along an outside surface of the transformer
insulation.

18. The apparatus according to any of the claims from 15 to 17, wherein the device (1) comprises:
- a membrane (5) permeable to the gas, interposed between a container (7) of the oil (2) and a measuring chamber (4) that receives a part of the gas through the membrane (5);
- a sensor (6) mounted in the measuring chamber (4) to measure a value of the gas concentration in the measuring chamber (4);
- a control unit (8) connected to the sensor (6) to derive an estimated value of gas concentration in the oil according to the value measured in the measuring chamber (4),
characterized in that the control unit (8) is designed to take, at successive measuring instants, a plurality of measurements of the values of gas concentration in the measuring chamber (4) and to calculate the estimated value of gas concentration in the oil at an instant selected from said measuring instants, according to a non-linear function of the values measured at the selected measuring instant and at one or more of the measuring instants preceding the one selected.
**INTERNATIONAL SEARCH REPORT**

**International application No**

PCT/IB2011/05Q081

**A. CLASSIFICATION OF SUBJECT MATTER**

INV. G01R31/12

ADD. G01N33/28

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

G01R G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>US 4 654 806 A (POYER THOMAS D [US] ET AL) 31 March 1987 (1987-03-31) table 1 figures 1-4</td>
<td>1, 2, 15</td>
</tr>
<tr>
<td>Y</td>
<td>col umn 3, line 18 - line 32 col umn 4, line 35 - line 46 col umn 7, line 25 - line 68 col umn 11, line 38 - col umn 13, line 11</td>
<td>3, 8, 13, 16-18</td>
</tr>
</tbody>
</table>

**X** Further documents are listed in the continuation of Box C. **X** See patent family annex.

* Special categories of cited documents:

-opening document defining the general state of the art which is not considered to be of particular relevance

-E- earlier document but published on or after the international filing date

-L- document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another document or to put the invention in a different context

-0- document referring to an oral disclosure, use, exhibition or other means

-P- document published prior to the international filing date but later than the priority date claimed

-T- later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

-X- document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is taken alone

-Y- document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

-A- document member of the same patent family

**Date of the actual completion of the international search**

24 March 2011

**Date of mailing of the international search report**

04/04/2011

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk
Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016

Authorized officer

Hof, Kl aus-Dieter

Form PCT/ISA210 (second sheet) (April 2000)
<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>page 258, col umn 1, line 13 - line 28 page 258, col umn 2, line 1 - line 12</td>
<td>1,15</td>
</tr>
<tr>
<td>Category</td>
<td>Citation of document, with indication, where appropriate, of the relevant passages</td>
<td>Relevant to claim No.</td>
</tr>
<tr>
<td>----------</td>
<td>----------------------------------------------------------------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>A</td>
<td>US 6 289 716 BI (LINDGREN STANLEY R [US])</td>
<td>5-7</td>
</tr>
<tr>
<td>A</td>
<td>WD 03/075294 AI (KOHLI ANIL [IN])</td>
<td>14, 18</td>
</tr>
<tr>
<td>Patent document cited in search report</td>
<td>Publication date</td>
<td>Patent family member(s)</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>US 4654806 A</td>
<td>31-03-1987</td>
<td>NONE</td>
</tr>
<tr>
<td>EP 1637879 A</td>
<td>22-03-2006</td>
<td>NONE</td>
</tr>
<tr>
<td>US 6289716 B1</td>
<td>18-03-2001</td>
<td>NONE</td>
</tr>
</tbody>
</table>