When the sensors are located inside the hull, far from it, the method allows a satisfactory determination of the magnetization of the hull corresponding to the measurements done.

However, the measurement in the air of the magnetic field created by the hull is disrupted. In fact, a ship contains secondary magnetic sources, such as the ferromagnetic masses that make up its engines. These secondary magnetic sources produce secondary magnetic fields that are superimposed on the magnetic field created by the hull. The secondary magnetic fields represent a strong disruption for the information one seeks to obtain by using the sensors. Also, the measurements are not very representative of the magnetic field resulting from the magnetization of the hull. As a result, the magnetization of the hull calculated from the measurements done inside the ship is not precisely representative of the actual magnetization of the hull. As a result, the signature of the ship thus calculated may be very different from the actual signature of the ship.

To improve the ratio of the relevant signal to the disruption, it has been considered to bring the sensors closer to the hull, to position them in the immediate vicinity thereof, and to move them away from the secondary magnetic sources as much as possible.

However, when the sensors are brought closer to the hull, the signature determined by the implementation of the method described in document FR 2 825 803 no longer corresponds to the actual signature of the ship.

~~The~~Embodiments of the invention therefore aim~~s~~ to offset this problem by ~~proposing~~providing a method for determining the magnetization of the hull of a ship making it possible to obtain, from magnetic field measurements done using sensors onboard the ship, a solution that ~~is~~may be robust and that ~~is~~may not be disrupted by parasitic magnetic field sources contained in the hull of the ship.

~~The invention therefore relates to~~According to a first aspect of the present invention, there is provided a method for the real-time determination of the magnetization of the hull of a ship, the hull of the ship being made from a ferromagnetic material and subjected to an inductive magnetic excitation, and the ship being provided with a plurality of magnetic field sensors positioned at predetermined points relative to the hull, comprising the following steps: a) - acquiring a plurality of measurements of the magnetic field using the plurality of sensors; b) - assessing the inductive magnetic excitation; and c) - determining a likely distribution of magnetic sources on the surface of the hull by resolving a system of equations derived from a modelization of the physical phenomena at play, on the basis of the plurality of measurements taken and the assessed inductive magnetic excitation~~,~~. ~~i~~In said modelization, the induced magnetic sources ~~being~~are described by a distribution of dipolar sources and the remanent magnetic sources ~~being~~are described ~~as~~by a distribution of monopolar sources. Said modelization comprises:

~~According to specific embodiments, the method comprises one or more of the following features, considered alone or according to all possible combinations:~~

~~- said modeling comprises:~~

- a first model associating a magnetization distribution in the ferromagnetic material with the measurements of the magnetic field; and

- a second model relative to the behavior of the ferromagnetic material, describing the coupling between a magnetic source at one point of the material, with a magnetic source at another point of the material;

According to specific embodiments, the method comprises one or more of the following features, considered alone or according to all possible combinations:

- the method uses a transform T making it possible to associate at least one distribution of monopolar sources with a distribution of dipolar sources and/or a transform T^* making it possible to associate at least one distribution of dipolar sources with a distribution of monopolar sources;

- said modelization uses a virtual model of the hull of the ship comprising a primary mesh made up of a plurality of planar and polygonal elementary surfaces;

- by elementary surface of the primary mesh, the distribution of dipolar sources is uniform and tangential to said surface element;

- the distribution of monopolar sources is discretized at the nodes of the primary mesh;

- said system of equations to be resolved is written:

$$\begin{pmatrix} A_M & A_M T^* \\ D_M + Id & D_M T^* \end{pmatrix} \begin{pmatrix} p_i^{ind} \\ Q_i^{rem} \end{pmatrix} = \begin{pmatrix} m \\ S_M \end{pmatrix}$$

with:

- m a vector whereof the jth component is the difference $H(R_j) - H_0(R_j)$ between the measurement of the magnetic excitation done at point R_j by the jth magnetic field sensors and the value of the inductive magnetic excitation at point R_j;

- A_M a matrix whereof the element $A_{M\,ji}$ is the operator $\frac{1}{4\pi}\int_{L_i}(u_i.\bar{n}_i)\frac{R_iR_j}{R_iR_j^3}dL_i(R_i)$ associated with an elementary surface S_i of the primary mesh having a plurality of edges L_i, each having a normal $\bar{n}_i$ in the plane of the elementary surface S_i and oriented toward the outside of said elementary surface, and where u_i is a pair of vectors forming a basis of the elementary surface;

- S_M is a vector whereof the ith component is proportional to the inductive magnetic excitation $e\chi H_{0i}$ at a point of the ith elementary surface of the primary mesh;

- D_M is a matrix whereof the element $D_{M\,ji}$ is the operator $-\frac{\chi e}{4\pi}\int_{L_i}(u_i.\bar{n}_i)\frac{R_jR_i}{|R_jR_i|^3}dL_i(R_i)$;

and

- T a transformation matrix such that $(Q_i^{rem}) = T(\bar{p}_i^{rem})$, whereof the pseudo-inverse is denoted T^*;

- the determination of the likely distribution of magnetic sources involves a preconditioning procedure;

- the determination of the likely distribution of magnetic sources involves a singular value decomposition procedure.

~~The invention also relates to~~According to a second aspect of the present invention, there is provided a method for the real-time determination of the magnetic signature of a ship, comprising a step for the real-time determination of the magnetization of the hull of the ship using the ~~preceding~~ method according to the first aspect, making it possible to obtain a likely distribution of magnetic sources on the surface of the hull, then an additional step consisting of calculating the signature of the ship from said likely distribution of magnetic sources.

~~The invention also relates to~~According to a third aspect of the present invention, there is provided a method for the magnetic immunization of a ship, the ship being provided with a plurality of immunization loops having predetermined geometries relative to the hull of the ship and power supply means capable of being controlled so as to cause suitable currents to circulate in the immunization loops, independently of one another, comprising, in addition to the steps of the ~~preceding~~ method according to the second aspect for the real-time determination of the signature of the ship, a step consisting of estimating the different currents to be circulated in the immunization loops~~,~~ so as to modify the signature of the ship, and a step consisting of controlling the power supply means so as to cause said estimated currents to circulate in the immunization loops.

~~The invention also relates to~~According to a fourth aspect of the present invention, there is provided a device for the real-time determination of the magnetization of the hull of a ship, the hull of the ship being made from a ferromagnetic material subjected to an inductive magnetic excitation~~. This device~~ characterized in that it comprises; a plurality of magnetic field sensors positioned at predetermined points relative to the hull; means for determining the inductive magnetic excitation; and a computation unit connected to the plurality of sensors and to the means for determining the inductive magnetic excitation, capable of executing the instructions of a computer program to implement the ~~preceding~~ method according to the first aspect for the real-time determination of the magnetization of the hull of a ship or the ~~preceding~~ method according to the second aspect for the real-time determination of the signature of a ship.

According to specific embodiments, the device comprises one or more of the following features, considered alone or according to all possible combinations:

- at least one sensor from the plurality of sensors is glued on the hull;

- at least one sensor from the plurality of sensors is a biaxial sensor measuring the components of the magnetic field that are tangential to the hull;

- at least one sensor from the plurality of sensors is placed outside the hull of the ship.

~~The invention also relates to~~According to a fifth aspect of the present invention, there is provided a device for the magnetic immunization of a ship of the type including a plurality of immunization loops having predetermined geometries relative to the hull of the ship, power supply means for the immunization loops, and means for controlling the power supply means of the immunization loops~~,~~. ~~t~~The control means including a device according to the fourth aspect ~~for the real-time determination of the magnetization of the hull~~ capable of calculating the signature of the ship.

The devices presented above ~~are~~may be advantageously onboard the ship whereof the magnetization of the hull is determined.

Embodiments of ~~T~~the invention and the advantages thereof will be better understood upon reading the following description, provided solely as an example, and done in reference to the appended drawings, in which:

- figure 1 is a diagrammatic illustration of the facility making it possible to regulate the signature of a ship;

- figure 2 is an illustration of a portion of the mesh of the hull and its dual meshing;

- figure 3 is a flowchart illustrating the regulation method; and

- figures 4 and 5 are graphs providing the value of the signature for different longitudinal positions under the hull of the ship.

Device

The ship for which one wishes to regulate the magnetic signature comprises a hull 1 that is made by assembling sheets of metal. The sheets of metal used are made from a ferromagnetic material characterized by a reversible magnetic susceptibility χ.

The hull has an inner surface 3, oriented toward the inside of the ship, and an outer surface 5, oriented toward the outside of the ship.

The ship contains a device, indicated by general reference 6 in figure 1, for the real-time determination of the magnetization of the hull of a ship. The device 6 is capable of implementing the methods for determining the magnetization of the hull of a ship, and for determining the signature of the ship and magnetic immunization of the ship.

The device 6 comprises a plurality of magnetic field sensors 7. For example, 50 sensors are positioned in the volume V2 inwardly delimited by the inner surface 3 of the hull 1. The sensors 7 are placed close to the inner surface 3 and, preferably, glued on that surface. From a practical standpoint, this is a mixture between biaxial and triaxial sensors. In the case at hand, the sensors 7 being glued to the hull or, at the very least, very close thereto, only the measurements of the components of the magnetic induction B tangent to the hull are taken into account. In fact, the measurement of the normal component of the magnetic induction B has an unfavorable signal-to-noise ratio and including it in models could be catastrophic in terms of convergence toward a robust solution, i.e. a solution that is stable relative to the measurement uncertainties. The information added by this normal component not being *very* representative, it is not taken into account in the

for the real-time determination of the signature of the ship, a step consisting of estimating the different currents to be circulated in the immunization loops so as to modify the signature of the ship, and a step consisting of controlling the power supply means so as to cause said estimated currents to circulate in the immunization loops.

11.- A device (6) for the real-time determination of the magnetization of the hull (1) of a ship, the hull of the ship being made from a ferromagnetic material subjected to an inductive magnetic excitation (H_0), characterized in that it comprises:

- a plurality of magnetic field sensors (7) positioned at predetermined points relative to the hull;
- means for determining the inductive magnetic excitation; and
- a computation unit (13) connected to the plurality of sensors and to the means for determining the inductive magnetic excitation, capable of executing the instructions of a computer program to implement the method according to any one of claims 1 to 8 for the real-time determination of the magnetization of the hull of a ship or the method according to claim 9 for the real-time determination of the signature of a ship.

12.- The device according to claim 11, characterized in that at least one sensor from the plurality (7) of sensors is glued on the hull (1).

13.- The device according to claim 11 or claim 12, characterized in that at least one sensor from the plurality of sensors (7) is a biaxial sensor measuring the components of the magnetic field that are tangential to the hull (1).

14.- The device according to any one of claims 11 to 13, characterized In that at least one sensor from the plurality of sensors (7) is placed outside the hull (1) of the ship.

15.- A device for the magnetic immunization of a ship of the type including a plurality of immunization loops having predetermined geometries relative to the hull (1) of the ship, power supply means (10) for the immunization loops, and means for controlling the power supply means of the immunization loops, characterized in that the control means include a device according to any one of claims 11 to 14 capable of calculating the signature of the ship.

16.- The device according to any one of claims 11 to 15, characterized in that it is onboard the ship whereof the magnetization of the hull is determined.