lead, tin, brass, aluminium or white metal, which may be used to hold the parts together (housings, bearings, etc.). Ferrous materials are normally soft ferromagnets, and for the purposes of this application the term "ferrous" will be used to describe the class of ferromagnetic materials comprising i.e. containing or consisting of iron (consistent with how it would normally be understood). Although non-ferrous ferromagnets, e.g. nickel and cobalt, also exist, most non-ferrous materials are paramagnetic or diamagnetic. Many non-ferrous materials only show a negligible paramagnetic or diamagnetic response to a magnetic field, and may essentially be classed as "non-magnetic".

The general principles behind metal detection using a magnetic field are well established, and the skilled person will understand that, and how, different metal particles may interact with an applied magnetic field. The basic concept is that an alternating magnetic field induces eddy currents in any conducting material, and will also be affected by the magnetic properties of the material. By detecting a resulting change in the magnetic field it is therefore possible to detect the presence of metals. Analysis of the signal may also allow classification of the material e.g. as ferromagnetic or non-ferromagnetic and/or a quantity of the material to be determined. The skilled person will also be aware of various established coil arrangements that can be used for measuring magnetic and conductive properties of metal particles within a test substance e.g. fluid.

Known coil arrangements fall into two main groups: either there are separate coils for transmitting and receiving a magnetic field, or the same coil effectively acts as both transmitter and receiver. An example of the latter arrangement is described in US patent no. 6,051,970 (HUTCHINGS). In US 6,051,970 a solenoidal coil is used to generate a magnetic field and a change in impedance of this coil in response to a sample being introduced into the field is monitored to detect the presence of metal particles. The development described in US 6,051,970 is the coaxial mounting of the solenoidal coil within a ferrite sleeve flux guide. As will be discussed further below the present inventors have recognised a number of problems associated with this sensor apparatus.

It is desired to provide an improved sensor apparatus, and in particular an improved coil arrangement for a sensor apparatus, for use in obtaining information relating to the presence of metal particles within a sample.

Accordingly, from a first aspect, the present invention provides a sensor apparatus for use in obtaining information relating to the presence of metal particles within a sample of a substance to be tested, the apparatus comprising:

a substrate comprising an aperture for receiving a sample of a substance to be tested, the substrate having one or more electrically conductive coils printed thereon;

magnetic field generating means for generating a magnetic field for application to a sample received in the aperture in use; and

sensing means for sensing the result of interaction between the generated magnetic field and a sample received in the aperture in use, the sensed result of the interaction being usable to determine a quantity of ferromagnetic e.g. ferrous particles in the sample;

individual metal particles within a dynamic sample e.g. a volume of fluid flowing through the aperture, e.g. within a test period.

These, and other, advantages that arise from embodiments of the present invention will be expanded upon in the discussion below. It will however be appreciated therefore that printing coils onto a substrate as described herein in providing a sensor apparatus for use in obtaining information relating to the presence of metal particles within a sample therefore provides a number of improvements over conventional mechanically wound coil arrangements like that described in US 6,051,970.

The sensing means senses the result of interaction between a magnetic field generated by the magnetic field generating means and the sample in use, i.e. when the magnetic field generating means is energised.

The sensing means may be seen as having a sensing region, the sensing means being arranged to sense the result of interaction between the generated magnetic field and the sample in the sensing region. As discussed in more detail below, the extent of the sensing region will depend upon the sensing means e.g. coil, and may also be influenced by the nature of the substance to be tested.

The sample of the substance to be tested in accordance with the present invention may be a static or a dynamic sample. In some embodiments the sample is a dynamic sample defined by a volume of fluid which flows through the aperture e.g. within a test period i.e. between a first time and a second time. In other embodiments the sample is a static sample i.e. an extracted volume of a substance to be tested.

The present invention also extends to a method of obtaining information relating to the presence of metal particles within a sample of a substance to be tested using the sensor apparatus of the present invention in accordance with any of the embodiments described herein. The method may comprise locating a sample of a substance to be tested such that it is received in said aperture; using the magnetic field generating means to generate a magnetic field; and using the sensing means to sense the result of interaction between the sample and the applied magnetic field. The sensed result of interaction may be a sensed result of interaction within a sensing region of the sensing means.

From yet another aspect, the present invention provides a method of obtaining information relating to the presence of metal particles within a sample using a sensor apparatus in accordance with the invention in any of its aspects or embodiments, the method comprising:

locating a sample of a substance to be tested such that the sample is received in said aperture;

using the magnetic field generating means to generate a magnetic field;

using the sensing means to sense the result of interaction between the sample and the applied magnetic field; and using the sensed result of interaction between the sample and the generated magnetic field to determine a quantity of ferromagnetic e.g. ferrous particles in the sample.

In accordance with a further aspect of the present invention there is provided a method of obtaining information relating to the presence of metal particles within a sample, the method comprising providing a sensor apparatus comprising:

particles detected in a given time period e.g. between first and second times defining the dynamic sample passing through the aperture or sensing region, and the volume of fluid in the sample. The count of individual metal particles is a cumulative total over the time period.

While in some cases it might be assumed that the rate of flow of fluid through the aperture (or more generally sensing region) is equivalent to the rate of flow of process fluid through a part of the system in which the sensor apparatus is disposed for testing, this assumption may not be appropriate, in particular in preferred embodiments in which the sensor apparatus samples only a fraction of the total fluid flowing through the part of the system e.g. pipe. The flow rate of fluid may, in any case, vary widely across the part of the system e.g. pipe. It is desirable, therefore, to determine more accurately the rate at which fluid may be considered to be flowing through the aperture (or sensing region). Preferably the method comprises using a flow sensor to determine data indicative of a rate of flow of fluid flowing through the aperture (or sensing region). The sensor apparatus may comprise the flow sensor, or may form part of a system including the sensor.

It is believed that incorporating a flow sensor into a sensor apparatus to enable counting of individual metal particles within a dynamic flow as a function of volume passing through a sensing region of the sensor is novel and advantageous in its own right, independent of the type of sensor apparatus or system being used to sense the individual metal particles. In other words, the sensor apparatus or system need not include the printed sensing coil surrounding an aperture of the earlier aspects of the invention.

Thus, in accordance with a further aspect of the invention there is provided a sensor apparatus for use in determining a count of individual metal particles with respect to volume for a dynamic sample provided by a volume of fluid flowing through a sensing region of the apparatus between first and second times, the apparatus comprising:

magnetic field generating means for generating a magnetic field for application to a sample in the sensing region;

sensing means comprising one or more electrically conductive coils for sensing the result of interaction between the generated magnetic field and a dynamic sample provided by a volume of fluid flowing through the sensing region between first and second times;

and a flow sensor for determining data indicative of the rate of fluid flow through the sensing region;

the sensed result of the interaction and the data indicative of the rate of fluid flow through the sensing region determined by the flow sensor being usable in determining a count of individual metal particles with respect to volume for the dynamic sample;

wherein the sensor apparatus is configured to be mounted to a part of a system comprising a fluid to be tested, such as a fluid pipe, and wherein the sensor apparatus is configured to sample only a portion of the fluid flow through the part of the system to which the apparatus is mounted.

The present invention in this further aspect may include any or all of the features described in relation to any of the other aspects of the invention to the extent they are not

mutually inconsistent. The present invention in this further aspect may be combined with and is compatible with any of the features of the sensor apparatus or systems described above in relation to any of the other aspects, and to any of the methods described above to the extent that they are not mutually incompatible.

Claims:

1. A sensor apparatus for use in obtaining information relating to the presence of metal particles within a sample of a substance to be tested, the apparatus comprising:

a substrate comprising an aperture for receiving a sample of a substance to be tested, the substrate having one or more electrically conductive coils printed thereon;

magnetic field generating means for generating a magnetic field for application to a sample received in the aperture in use; and

sensing means for sensing the result of interaction between the generated magnetic field and a sample received in the aperture in use, the sensed result of the interaction being usable to determine a quantity of ferromagnetic e.g. ferrous particles in the sample;

wherein the substrate includes an electrically conductive coil printed thereon that circumferentially surrounds said aperture for receiving the sample, the electrically conductive coil forming part of said sensing means.

2. The sensor apparatus of claim 1, wherein the quantity is a total content e.g. mass of the particles per unit volume.

3. The sensor apparatus of claim 1 or 2, wherein the sample is an extracted sample contained within a sample container, such as a test tube.

4. The sensor apparatus of claim 1 or 2, wherein the sample is a dynamic sample defined by a volume of fluid which flows through the aperture between first and second times.

5. The sensor apparatus of any of claims 1, 2 or 3 wherein the sensor apparatus forms part of a sensor unit, the sensor unit further comprising a housing, wherein said housing comprises an opening coaxial with said aperture of the sensor apparatus to enable a sample to be tested to be received within the aperture, optionally wherein the sensor unit is a portable unit.

6. The sensor apparatus of any preceding claim wherein at least the coil surrounding the aperture and forming part of the sensing means comprises multiple coil portions printed at different respective levels of the substrate; or wherein the substrate comprises multiple substrate layers, and wherein at least the coil surrounding the aperture and forming part of the sensing means comprises coil portions printed on more than one layer of the substrate, each coil portion being printed at a different respective level of the substrate.

7. The sensor apparatus as claimed in any preceding claim wherein at least the coil surrounding the aperture is a spiral coil and/or wherein the or each coil portion of at least the conductive coil surrounding the aperture is a spiral coil portion.

8. The sensor apparatus of any preceding claim wherein the sensor apparatus comprises a printed circuit board (PCB) defining the substrate and comprising at least the aperture, the sensing means and optionally the magnetic field generating means.

9. The sensor apparatus as claimed in any preceding claim, wherein the printed conductive coil circumferentially surrounding said aperture that forms part of the sensing means also forms part of said magnetic field generating means.

10. The sensor apparatus as claimed in any preceding claim, wherein said sensing means is arranged to sense a change in impedance of the conductive coil resulting from said interaction between the sample fluid and the generated magnetic field.

11. The sensor apparatus of any preceding claim wherein the sensor apparatus comprises means for generating data indicative of the sensed result of the interaction between the sample and the generated magnetic field.

12. The sensor apparatus of claim 11 comprising means for providing the generated data indicative of the sensed result to one or more of; output means e.g. a display for outputting information to a user based on the data indicative of the sensed result, storage means for storing data based on the data indicative of the sensed result, and processing means for using the data indicative of the sensed result in obtaining information relating to the presence of metal particles within the sample.

13. The sensor apparatus of claim 12 wherein the sensor apparatus comprises any one or ones of said storage means, output or processing means and/or wherein any one or ones of the storage means, output or processing means are remote from the sensor apparatus, wherein the sensor apparatus further comprises means for transmitting the generated data indicative of the sensed result thereto.

14. The sensor apparatus of any preceding claim further comprising processing means for using the sensed result of said interaction to determine a quantity of ferromagnetic e.g. ferrous particles within the sample.

15. A system comprising the sensor apparatus of any one of claims 1 to 14 and processing means remote from the sensor apparatus for using the sensed result of said interaction to determine a quantity of ferromagnetic e.g. ferrous particles within the sample.

16. The apparatus or system as claimed in any preceding claim, further comprising a reference component for calibrating or balancing said sensing means, wherein said reference component comprises a reference coil printed on the substrate, preferably wherein the reference coil is identical to the printed coil of the sensing means.

17. An apparatus or system as claimed in any preceding claim, further comprising electrostatic shielding disposed between the conductive coil of said sensing means and the aperture, preferably wherein said electrostatic shielding comprises an incomplete ring printed on said substrate.

18. A method of obtaining information relating to the presence of metal particles within a sample using the sensor apparatus or system of any preceding claim, optionally wherein the method comprises:

locating a sample of a substance to be tested such that it is received in said aperture;

using the magnetic field generating means to generate a magnetic field;

using the sensing means to sense the result of interaction between the sample and the applied magnetic field; and

using the sensed result of interaction between the sample and the generated magnetic field to determine a quantity of ferromagnetic e.g. ferrous particles in the sample.

19. The method of claim 18, wherein the method comprises determining a total content e.g. mass of the particles per unit volume.

20. A sensor apparatus for use in determining a count of individual metal particles with respect to volume for a dynamic sample provided by a volume of fluid flowing through a sensing region of the apparatus between first and second times, the apparatus comprising:

magnetic field generating means for generating a magnetic field for application to a sample in the sensing region;

sensing means comprising one or more electrically conductive coils for sensing the result of interaction between the generated magnetic field and a dynamic sample provided by a volume of fluid flowing through the sensing region between first and second times;

and a flow sensor for determining data indicative of a rate of fluid flow through the sensing region;

the sensed result of the interaction and the data indicative of the rate of fluid flow through the sensing region determined by the flow sensor being usable in determining a count of individual metal particles with respect to volume for the dynamic sample,

wherein the sensor apparatus is configured to be mounted to a part of a system comprising a fluid to be tested, such as a fluid pipe, and wherein the sensor apparatus is configured to sample only a portion of the fluid flow through the part of the system to which the apparatus is mounted.

21. The apparatus of claim 20 wherein the or each electrically conductive coil of the sensing means is a printed coil.

22. A method of using the sensor apparatus of claim 20 or 21 in determining data for use in determining a count of individual metal particles with respect to volume for a dynamic sample provided by a volume of fluid flowing through a sensing region of the apparatus between first and second times, wherein the sensor apparatus is disposed such that the sensing region receives only a portion of the fluid flow of the system in the region of the sensor apparatus,

the method comprising using the sensing means to sense the result of interaction between the dynamic sample and an applied magnetic field, and using the flow sensor to determine data indicative of the rate of fluid flowing through the sensing region.