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SAMPLE ANALYZER

Abstract

An object of the present invention is to provide a sample analyzer that is less likely to cause positional deviation of a magnetic field in a channel regardless of an occurrence of positional deviation of a magnet and that enables highly accurate analysis. To attain this purpose, the present invention provides a sample analyzer including: a channel that introduces a sample liquid containing a magnetic particle bound to a labeling substance; a liquid feeding unit that supplies and discharges the sample liquid into and from the channel; a magnetic field applying unit that applies a magnetic field for capturing the magnetic particle in the channel; and a detector that detects the labeling substance bound to the magnetic particle that has been captured. The magnetic field applying unit includes a plurality of members, and at least one of the members is formed integrally with the channel.

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Background/Summary

TECHNICAL FIELD

[0001] The present invention relates to a sample analyzer.

BACKGROUND ART

[0002] A sample analyzer such as an immunoassay analyzer introduces a sample liquid containing magnetic particles bound to a labeling substance into a channel such as a flow cell, captures (adsorbs) the magnetic particles in the channel, and applies an external electric field or the like to the captured magnetic particles to cause the labeling substance bound to the magnetic particles to emit light. The emission intensity at that time is detected, whereby an amount of the detection substance bound to the magnetic particles can be measured.

[0003] For example, PTL 1 describes a sample analyzer that collects magnetic particles by bringing a magnet close to a channel to strengthen a magnetic field when detecting emission intensity, and discharges the magnetic particles by moving the magnet away from the channel to weaken the magnetic field when cleaning the inside of the channel.

CITATION LIST

Patent Literature

[0004] PTL 1: WO 2011/155489 A

SUMMARY OF INVENTION

Technical Problem

[0005] However, in a case where a mechanism in which a magnet as a magnetic field generation source moves is used, the number of components for holding the mechanism or operating the mechanism increases, and thus, the degree of freedom related to positioning increases, and when the mechanism is repeatedly used, positional deviation may occur. Even if the mechanism in which the magnet moves is not used, there is a possibility of positional deviation of the magnet when the components are operated for maintenance or the like. When a magnetic field in the channel deviates due to the positional deviation of the magnet, the magnetic particles cannot be reliably captured, so that the accuracy of analysis is reduced.

[0006] An object of the present invention is to provide a sample analyzer that is less likely to cause positional deviation of a magnetic field in a channel regardless of an occurrence of positional deviation of a magnet and that enables highly accurate analysis.

Solution to Problem

[0007] To address the above-mentioned problem, the present invention provides a sample analyzer including: a channel that introduces a sample liquid containing a magnetic particle bound to a labeling substance; a liquid feeding unit that supplies and discharges the sample liquid into and from the channel; a magnetic field applying unit that applies a magnetic field for capturing the magnetic particle in the channel; and a detector that detects the labeling substance bound to the magnetic particle that has been captured, wherein the magnetic field applying unit includes a plurality of members, and at least one of the members is formed integrally with the channel.

Advantageous Effects of Invention

[0008] The present invention can provide a sample analyzer that is less likely to cause positional deviation of a magnetic field in a channel regardless of an occurrence of positional deviation of a magnet and that enables highly accurate analysis.

Description

BRIEF DESCRIPTION OF DRAWINGS

[0009] FIG. **1** is a diagram illustrating a schematic configuration of an immunoassay analyzer.

[0010] FIG. **2** is a diagram illustrating configurations of a magnetic field applying unit and a flow cell according to a first embodiment.

[0011] FIG. **3** is a diagram illustrating a magnetic field generation source and the flow cell when positional deviation occurs.

[0012] FIG. **4** is a diagram illustrating an analysis model according to a comparative example that does not use a fixed magnetic material.

[0013] FIG. **5** is a diagram illustrating an analysis model according to the first embodiment that uses a fixed magnetic material.

[0014] FIG. **6** is a diagram showing analysis results of magnetic flux densities for the analysis model according to the comparative example and the analysis model according to the first embodiment.

[0015] FIG. **7** is a diagram illustrating an analysis model according to a second embodiment in which a fixed magnetic material is in contact with a core.

[0016] FIG. **8** is a diagram showing analysis results of magnetic flux densities for the analysis model according to the comparative example and the analysis model according to the second embodiment.

[0017] FIG. **9** is a diagram illustrating an analysis model according to a third embodiment in which an end face of the fixed magnetic material on the channel side has a smaller area.

[0018] FIG. **10** is a diagram showing analysis results of magnetic flux densities for the analysis model according to the comparative example and the analysis model according to the third embodiment.

[0019] FIG. **11** is a diagram illustrating a plurality of modifications regarding the shape of the fixed magnetic material.

[0020] FIG. **12** is a cross-sectional view illustrating a distribution of a magnetic flux density in a representative shape example of the fixed magnetic material.

[0021] FIG. **13** is a diagram illustrating configurations of a magnetic field applying unit and a flow cell according to a fourth embodiment.

[0022] FIG. **14** is a diagram illustrating an analysis model according to the fourth embodiment in which a fixed magnetic material is provided on a channel top wall.

[0023] FIG. **15** is a diagram showing analysis results of magnetic flux densities for the analysis model according to the comparative example and the analysis model according to the fourth embodiment.

[0024] FIG. **16** is a diagram illustrating configurations of a magnetic field applying unit and a flow cell according to a fifth embodiment.

[0025] FIG. **17** is a diagram illustrating configurations of a magnetic field applying unit and a flow cell according to a sixth embodiment.

[0026] FIG. **18** is a diagram illustrating configurations of a magnetic field applying unit and a flow cell according to a seventh embodiment.

[0027] FIG. **19** is a diagram illustrating configurations of a magnetic field applying unit and a flow cell according to an eighth embodiment.

[0028] FIG. **20** is a diagram illustrating configurations of a magnetic field applying unit and a flow cell according to a ninth embodiment.

DESCRIPTION OF EMBODIMENTS

[0029] A preferred embodiment of the present invention will be described below with reference to the drawings.

[0030] In the present preferred embodiment, an immunoassay analyzer will be described as an example of the sample analyzer. It is to be noted that the present invention is not limited to be used for immune assay, and can be applied to any sample analyzer as long as the sample analyzer captures magnetic particles by switching the magnetic field intensity using the magnetic particles. For example, the present invention can be applied to an analyzer for DNA assay, biochemical assay, or the like. In addition, the preferred embodiment described below is not limited in terms of shapes, dimensions, numbers, and the like, and can be modified without departing from the gist thereof.

[0031] FIG. **1** is a diagram illustrating a schematic configuration of an immunoassay analyzer. The immunoassay analyzer includes a channel **10**, a liquid feeding unit, a magnetic field applying unit, a photodetector **23**, a controller **50**, and the like. The channel **10** is a section into which a sample liquid containing magnetic particles **13** bound to a labeling substance is introduced, and is defined by a channel top wall **11** and a channel bottom wall **12**. In the present specification, a detection unit including the channel top wall **11**, the channel bottom wall **12**, a reaction field electrode **14**, and a counter electrode **15** is referred to as a flow cell as an integrated member.

[0032] The channel top wall **11** is preferably made of a transparent material such as glass or plastic. Thus, the photodetector **23** can detect the wavelength of light emitted from the labeling substance bound to the magnetic particles **13** around the reaction field electrode **14**.

[0033] The reaction field electrode **14** is provided around the bottom of the channel **10**, and the counter electrode **15** is provided to face the reaction field electrode **14** across the channel **10**, that is, provided around the upper part of the channel **10**. Further, the reaction field electrode **14** and the counter electrode **15** are connected to a voltage applying unit **16** via signal lines **55***b* and **55***c*. The voltage applying unit **16** is connected to the controller **50** via a signal line **55***a*.

[0034] The materials of the reaction field electrode **14** and the counter electrode **15** can be, for example, gold, platinum, palladium, tungsten, iridium, nickel, alloys thereof, carbon materials, and the like. Further, a material obtained by depositing the above materials into a film shape on a base material such as titanium by plating, sputtering, or the like, for example, can also be used as the reaction field electrode **14** and the counter electrode **15**.

[0035] The reaction field electrode **14** basically has a planar shape in terms of ease of measurement of light emission, and is provided on the bottom surface of the channel **10**. However, the reaction field electrode **14** may be provided on another surface in the channel **10** or on a plurality of surfaces arranged three-dimensionally. The reaction field electrode **14** is not limited to have a planar shape as long as it is suitable for capturing the magnetic particles **13** or for electrochemical luminescence of the labeling substance bound to the magnetic particles **13**, and may have a linear shape, a combination of a linear shape and a planar shape, or the like. The counter electrode **15** may be provided at any position and may have any shape as long as it can generate a voltage in the channel **10** in combination with the reaction field electrode **14**, and may have a linear shape, a planar shape, or a combination thereof.

[0036] In the present preferred embodiment, the magnetic field applying unit that applies a magnetic field for capturing the magnetic particles **13** in the channel **10** includes a magnetic field generation source and a fixed magnetic material **22** for inducing a magnetic field from the magnetic field generation source to the reaction field electrode **14**. The magnetic field generation source may be an electromagnet or a permanent magnet.

[0037] In FIG. **1**, an electromagnet including a coil **20** and a core **21** is used as the magnetic field generation source.

[0038] As the coil **20**, a popular solenoid coil or the like can be used as long as a magnetic field can be generated as an electromagnet, and for example, a solenoid coil made of a solid or stranded copper wire can be used. In addition, popular soft magnetic materials such as iron, silicon steel, permalloy, permendur, magnetic alloy, or soft ferrite can be used as the core **21** and the fixed magnetic material **22** as long as a magnetic field can be generated or induced. The core **21** and the fixed magnetic material **22** may be formed of the same soft magnetic material or different soft magnetic materials.

[0039] The electromagnet including the coil **20** and the like is connected to the controller **50** via signal lines **56***a* and **56***b* and a voltage applying unit **17**. When the magnetic particles **13** are captured (adsorbed), the voltage applying unit **17** is controlled by the controller **50**, by which a voltage is applied to the coil **20**. Thus, a magnetic field is generated around the reaction field electrode **14** and the counter electrode **15** in the channel **10**. The magnetic particles **13** are collected on the reaction field electrode **14** by magnetic force derived from the generated magnetic field. When a voltage is applied to the coil **20**, either a direct current or an alternate current may be used as long as the electromagnet including the coil **20** and the like can generate a magnetic field. When an alternate current is used, it is preferable to take a common measure against a skin effect such as using a stranded wire.

[0040] In a case where the magnetic field generation source is a permanent magnet, a movable arm and a permanent magnet, for example, are installed near the reaction field electrode **14**, and the arm is moved by a signal from the controller **50** to change the distance between the permanent magnet and the reaction field electrode **14**, as will be described later with reference to FIG. **20**. According to this method, even when a permanent magnet is used as the magnetic field generation source, it is possible to control an increase and decrease of the magnetic field in the channel **10** as in the case of using the electromagnet.

[0041] The voltage applying unit **16** is controlled by the controller **50**. When a voltage is applied between the reaction field electrode **14** and the counter electrode **15** in the channel **10** in response to a command from the controller **50** to the voltage applying unit **16**, the labeling substance bound to the magnetic particles **13** captured on the reaction field electrode **14** can electrochemically emit light.

[0042] The photodetector **23** detects the labeling substance bound to the magnetic particles **13** captured by the magnetic field applied by the magnetic field applying unit, and is, for example, a camera, a photomultiplier tube, or the like. The photodetector **23** can detect a wavelength of light emitted from the labeling substance around the reaction field electrode **14**, and operates by a signal from the controller **50**.

[0043] The liquid feeding unit is a unit for supplying and discharging a sample liquid into and from the channel **10** in the flow cell, and includes a tube, a pump, a valve, and the like. The channel **10** is connected to a sipper nozzle **30** and a pump **35** through a tube **32** and a tube **33**. The sipper nozzle **30** is attached to be movable by an arm **31**, and a suspension container **40**, a cleaning liquid container **42**, and a buffer solution container **43** are installed within the range of movement of the sipper nozzle **30**. The tube **33** between the channel **10** and the pump **35** is provided with a valve **36**. The pump **35** and the valve **36** are connected to the controller **50** through signal lines **52** and **53**, and are connected to a waste container **45** through a valve **37** and a tube **34**.

[0044] The controller **50** is connected to the valves **36** and **37**, the pump **35**, the arm **31**, the voltage applying units **16** and **17**, and the photodetector **23** by independent signal lines **51**, **52**, **53**, **54**, **55***a*, **56***a*, and **57**, respectively. As a result, the controller **50** can independently control the components connected thereto.

[0045] A sample to be analyzed is a substance derived from a living body such as serum or urine. When the sample is serum, a specific component to be analyzed is, for example, a tumor marker, an antibody, an antigen-antibody complex, or a single protein. In the following description, the specific component is a thyroid stimulating hormone (TSH).

[0046] The suspension container **40** stores a sample to be analyzed that is mixed with a bead solution and a reagent and then reacted at a certain temperature (for example, 37 degrees) for a certain period of time as a pretreatment process. The bead solution is prepared by dispersing the magnetic particles **13** in which a particulate magnetic substance is embedded in a matrix material such as polystyrene in a buffer solution, and streptavidin capable of binding to biotin is bound to the surface of the matrix material. The reagent contains a substance that binds the magnetic particles **13** to the specific component TSH in the sample, and includes an anti-thyroid stimulating hormone (TSH) antibody whose terminal is treated with biotin. The reagents vary depending on the type of specific component to be analyzed, and for example, immunoglobulins, antigens, antibodies, or other biological substances are used.

[0047] The cleaning liquid container **42** stores a cleaning liquid for cleaning the inside of the channel **10** and the tube **32**.

[0048] When a length in the direction along the flow (path length) and a thickness (vertical direction) and a width (horizontal direction) of the cross section perpendicular to the flow are defined, the channel **10** preferably has a shape in which the path length is 2 to 20 times longer than the larger one of the thickness and the width. This is because, by sufficiently ensuring the path, the magnetic particles **13** in a fluid spread in the channel **10** and then are easily captured on the reaction field electrode **14** provided on the bottom surface of the channel **10**.

[0049] The capture distribution of the magnetic particles **13** in the channel **10** is determined by a magnetic force received from the magnet (electromagnet or permanent magnet) installed in the vicinity of the channel **10** and the drag force due to the flow of the fluid. The magnetic field in the channel **10** preferably has a magnetic flux density of about 0.1 to 0.5 T. The flow velocity of the fluid at that time is preferably about 0.05 to 0.10 m/s.

[0050] The particles described below are preferably used as the magnetic particles **13**.

[0051] (1) Particles exhibiting paramagnetism, superparamagnetism, ferromagnetism, or ferrimagnetism, and (2) particles obtained by encapsulating particles exhibiting paramagnetism, superparamagnetism, ferromagnetism, or ferrimagnetism in a material such as a synthetic polymer compound (polystyrene, nylon, etc.), a natural polymer (cellulose, agarose, etc.), or an inorganic compound (silica or the like). The particle size is preferably in the range of 0.01 to 200 μm, and more preferably in the range of 1 to 10 μm. The specific gravity is preferably 1.3 to 1.5. According to this specification, the magnetic particles **13** are less likely to settle in the liquid and are likely to be suspended. A substance having a property of specifically binding to the substance to be analyzed, for example, an antibody having a property of specifically binding to an antigen, is bound to the surface of the particle.

[0052] The substances described below are preferably used as the labeling substance. Specifically, the following substances are described as examples from the viewpoint of specifically binding the labeling substance to the substance to be analyzed by an appropriate means and allowing the labeling substance to emit light by an appropriate means.

[0053] (1) A labeling substance used in fluorescence immunoassay. For example, an antibody labeled with fluorescein isothiocyanate or the like.

[0054] (2) A labeling substance used in chemiluminescent immunoassay. For example, an antibody labeled with acridinium ester or the like.

[0055] (3) A labeling substance used in chemiluminescent enzyme immunoassay. For example, an antibody labeled with a chemiluminescent enzyme using luminol or an adamantyl derivative as a luminescent substrate.

[0056] The configuration of the immunoassay analyzer has been described above. Next, the operation of the immunoassay analyzer will be described. Regarding the operation, one analysis is defined as one cycle, and a state in which the immunoassay analyzer continuously performs the cycle a plurality of times is defined as a basic device operating state.

[0057] One cycle of analysis includes a suspension aspiration period, a magnetic particle capturing period, a detection period, a cleaning period, a reset period, and a preliminary aspiration period. One cycle is started when the suspension container **40** containing a suspension treated in a reaction unit **41** is set in a predetermined position.

[0058] During the suspension aspiration period, the valve **36** is opened and the valve **37** is closed. In response to a signal from the controller **50**, the arm **31** is operated to insert the sipper nozzle **30** into the suspension container **40**. Subsequently, the pump **35** performs a certain amount of aspiration operation in response to a signal from the controller **50**. Aspirated by the fluid in the tube **32**, the suspension in the suspension container **40** enters the tube **32** through the sipper nozzle **30**.

In this state, the pump **35** is stopped, and the arm **31** is operated to insert the sipper nozzle **30** into a cleaning mechanism **44**. When passing through the cleaning mechanism **44**, the sipper nozzle **30** is cleaned.

[0059] During the magnetic particle capturing period, a voltage is applied in response to a signal from the controller **50**, so that the electromagnet including the coil **20** and the like operates. The pump **35** aspirates at a constant speed in response to a signal from the controller **50**. Meanwhile, the suspension present in the tube **32** passes through the channel **10**. A magnetic field by the electromagnet is generated in the channel **10**, and thus, the magnetic particles **13** contained in the suspension are attracted toward the channel bottom wall **12** by magnetic force and captured on the reaction field electrode **14**.

[0060] During the detection period, the application of voltage to the electromagnet is stopped in response to a signal from the controller **50**. Subsequently, in response to a signal from the controller **50**, the photodetector **23** is operated, and a voltage is applied to the reaction field electrode **14** and the counter electrode **15**. Thus, light emitted from the labeling substance bound to the magnetic particles **13** is received by the photodetector **23** with the magnetic particles **13** being held on the reaction field electrode **14**, whereby the measurement can be performed. The detected intensity of the emitted light is collected by the controller **50** as a signal. After a lapse of a certain time, the application of voltage to the reaction field electrode **14** and the counter electrode **15** and the operation of the photodetector **23** are stopped. During the detection period, the arm **31** is operated to insert the sipper nozzle **30** into the cleaning mechanism **44**.

[0061] During the cleaning period, the cleaning liquid aspirated from the cleaning liquid container **42** passes through the channel **10** by aspiration using the pump **35**. At this time, the electromagnet is in a non-operating state, whereby the magnetic **13** are not held on the reaction field electrode **14** and are washed away together with the cleaning liquid.

[0062] During the reset period, the valve **36** is closed, the valve **37** is opened, and the pump **35** performs a discharge operation. The liquid in the pump **35** is discharged to the waste container **45**.

[0063] During the preliminary aspiration period, the buffer solution is aspirated from the buffer solution container **43**, and the tube **32** and the channel **10** are filled with the buffer solution. After the preliminary aspiration period, the next one cycle can be started.

[0064] Regarding the sample analyzer according to the present preferred embodiment described above, a specific structure of the magnetic field applying unit will be described below by way of first to ninth embodiments.

First Embodiment

[0065] The structure of a sample analyzer according to the first embodiment will be described in detail with reference to FIGS. **2** and **3**. In the present embodiment, an electromagnet is used as a magnetic field generation source. In sample analyzers, a magnetic field around the reaction field electrode **14** may vary due to individual differences in manufacturing, a change in use environment, a decrease in operating current due to heat generation, and the like. However, in the sample analyzer using an electromagnet as in the present embodiment, a desired magnetic field can be obtained without movement of the electromagnet by, for example, adjusting a load voltage (current) to the electromagnet or changing an operating time.

[0066] FIG. **2** is a diagram illustrating configurations of a magnetic field applying unit and a flow cell according to the first embodiment, and illustrates a cross section on a ZX plane when a coordinate system is used in which a traveling direction of flow in the channel **10** is an x axis, a horizontal direction of the cross section perpendicular to the flow is a y axis, and the vertical direction thereof is a z axis. The magnetic particles **13** flow in the channel **10** of the flow cell along a flow direction **61**. Note that FIG. **2** does not illustrate the counter electrode **15**.

[0067] A magnetic field applying unit is provided below the reaction field electrode **14** of the flow cell. When a mechanism for moving the permanent magnet close to or away from the flow cell is used as the magnetic field applying unit, the number of components for holding the mechanism or operating the mechanism increases, and thus, the degree of freedom related to positioning increases, and when the mechanism is repeatedly used, positional deviation may occur. On the other hand, in a case where an electromagnet is used as the magnetic field applying unit as in the present embodiment, it is not necessary to move the magnetic field generation source, so that positional deviation is relatively less likely to occur. However, even in the case of using an electromagnet, the electromagnet may deviate when components are operated due to maintenance or the like.

[0068] In view of this, in the present embodiment, the magnetic field applying unit is constituted by a plurality of members, and a fixed magnetic material **22** among the components is integrally formed with the flow cell. Therefore, even when the magnetic field generation source (the coil **20** and the core **21**), which another member constituting the magnetic field applying unit, deviate, the fixed magnetic material **22** does not deviate, and thus, imbalance in the magnetic field around the reaction field electrode **14** is reduced.

[0069] In addition, the fixed magnetic material **22** is provided on the channel bottom wall **12**, and the distance between the channel **10** and the fixed magnetic material **22** is minimum on the bottom surface side of the channel **10**. That is, the fixed magnetic material **22** is interposed between the magnetic field generation source and the reaction field electrode **14**, whereby the magnetic field generated by the magnetic field generation source can be effectively guided to the reaction field electrode **14**.

[0070] Examples of a method for integrating the fixed magnetic material **22** with the flow cell include a method for fixing the fixed magnetic material **22** by bonding the fixed magnetic material to the channel wall with an adhesive or the like after the manufacture of the flow cell, and a method for fixing the fixed magnetic material **22** by embedding the fixed magnetic material in the channel wall by insert molding in the process of manufacturing the flow cell. When the fixed magnetic material **22** is joined to the flow cell so as to be exposed toward the magnetic field generation source, the fixed magnetic material **22** can be brought close to the magnetic field generation source, so that the magnetic flux leaking from the magnetic field generation source into the air can be reduced. Thus, a decrease in the magnetic field on the reaction field electrode **14** can be suppressed. On the other hand, in a case where the fixed magnetic material **22** is embedded in the channel bottom wall **12**, the fixed magnetic material **22** is distant from the magnetic field generation source, so that the magnetic field reaching the fixed magnetic material **22** is weakened. However, the fixed magnetic material **22** is close to the channel **10**, so that the deviation of the magnetic field with respect to the channel space is less likely to occur.

[0071] FIG. **3** is a diagram illustrating the magnetic field generation source and the flow cell when positional deviation occurs. The position of the electromagnet including the coil **20** and the core **21** disposed below the flow cell moves to the upstream side (−x direction) of the channel, so that positional deviation occurs. The distance from the end of the reaction field electrode **14** on the upstream (−x) side of the channel to the electromagnet decreases, while the distance from the end of the reaction field electrode **14** on the downstream (+x) side of the channel to the electromagnet increases. As a result, in a case where the fixed magnetic material **22** is not used, imbalance is caused in the magnetic field generated from the electromagnet by an operation of the electromagnet between the upstream side of the channel and the downstream side of the channel with respect to the reaction field electrode **14**.

[0072] When the magnetic particles **13** are captured on the reaction field electrode **14**, it is preferable to capture the magnetic particles **13** uniformly and at a high rate on the reaction field electrode **14**. However, if imbalance is caused in the magnetic field around the reaction field electrode **14**, the distribution or efficiency at the time of capturing the magnetic particles **13** deteriorates.

[0073] In view of this, in the present embodiment, the magnetic field generated from the electromagnet is guided to the reaction field electrode **14** via the fixed magnetic material **22** to thereby reduce imbalance in the magnetic field around the reaction field electrode **14**. This makes it possible to suppress deterioration of distribution or efficiency at the time of capturing the magnetic particles **13** on the reaction field electrode **14** even when the magnet of the magnetic field generation source deviates.

[0074] Regarding the effect of suppressing the positional deviation of the magnetic field according to the present embodiment, the results confirmed by magnetic field analysis will be described with reference to FIGS. **4**, **5**, and **6**.

[0075] FIG. **4** illustrates an analysis model in which a fixed magnetic material is not used as a comparative example. FIG. **4**(*a*) illustrates a case where the electromagnet including the coil **20** and the core **21** does not deviate, and FIG. **4**(*b*) illustrates a case where the electromagnet deviates by a dimension B**1** in the x direction from the state illustrated FIG. **4**(*a*). A position **81** where the magnetic field is desired to be strengthened is indicated at a spatial position that is supposed to be a position on the reaction field electrode **14**, and a channel-upstream-side adjacent portion **82** and a channel-downstream-side adjacent portion **83** which are adjacent to the position **81** are indicated. In FIG. **4**(*a*), the center position of the position **81** where the magnetic field is desired to be strengthened on the xy plane is the same as the center position of the core **21** on the xy plane. Regarding the shape and dimension of the analysis model, the position and dimension of the core in the horizontal direction is represented by A**1**, the position and dimension of the core in the vertical direction is represented by A**2**, the upper core length is represented by A**3**, the coil length is represented by A**4**, the lower core length is represented by A**5**, the coil diameter is represented by A**6**, and the core diameter is represented by A**7**. Further, regarding the dimensions of the position **81** where the magnetic field is desired to be strengthened, the channel-upstream-side adjacent portion **82**, and the channel-downstream-side adjacent portion **83**, the x-axis dimension of the position where the magnetic field is desired to be strengthened is represented by L**1**, the x-axis dimension of the channel-upstream-side adjacent portion is represented by L**2**, and the x-axis dimension of the channel-downstream-side adjacent portion is represented by L**3**.

[0076] FIG. **5** illustrates an analysis model according to the first embodiment in which a fixed magnetic material is used. FIG. **5**(*a*) illustrates a case where the electromagnet including the coil **20** and the core **21** does not deviate, and FIG. **5**(*b*) illustrates a case where the electromagnet deviates by a dimension B**1** in the x direction from the state illustrated FIG. **5**(*a*). A position **81** where the magnetic field is desired to be strengthened is indicated at a spatial position that is supposed to be a position on the reaction field electrode **14**, and a channel-upstream-side adjacent portion **82** and a channel-downstream-side adjacent portion **83** which are adjacent to the position **81** are indicated. Regarding the shape and dimension of the analysis model, the position and dimension of the core in the horizontal direction is represented by A**1**, the position and dimension of the core in the vertical direction is represented by A**2**, the upper core length is represented by A**3**, the coil length is represented by A**4**, the lower core length is represented by A**5**, the coil diameter is represented by A**6**, the core diameter is represented by A**7**, the gap between the fixed magnetic material and the core is represented by A**8**, and the length of the fixed magnetic material is represented by A**9**. Further, regarding the dimensions of the position **81** where the magnetic field is desired to be strengthened, the channel-upstream-side adjacent portion **82**, and the channel-downstream-side adjacent portion **83**, the x-axis dimension of the position where the magnetic field is desired to be strengthened is represented by L**1**, the x-axis dimension of the channel-upstream-side adjacent portion is represented by L**2**, and the x-axis dimension of the channel-downstream-side adjacent portion is represented by L**3**. The fixed magnetic material **22** is fixed to the flow cell, and thus, it can be seen from FIGS. **5**(*a*) and **5**(*b*) that only the coil **20** and the core **21** are moved with the relative position between the fixed magnetic material **22** and the position **81** where the magnetic field is desired to be strengthened being unchanged.

[0077] In FIGS. **4** and **5**, the position and dimension A**1** of the core in the horizontal direction is set to 0.5 mm, the position and dimension A**2** of the core in the vertical direction is set to 0.5 mm, the upper core length A**3** in FIG. **4** is set to 5 mm, the upper core length A**3** in FIG. **5** is set to 3 mm, the coil length A**4** is set to 60 mm, the lower core length A**5** is set to 5 mm, the coil diameter A**6** is set to 17 mm, the core diameter A**7** is set to 7 mm, the positional deviation dimension B**1** is set to 0 to 2 mm, the gap A**8** between the fixed magnetic material and the core is set to 0.5 mm, and the length of the fixed magnetic material A**9** is set to 2 mm. In addition, the x-axis dimension L**1** of the position where the magnetic field is desired to be strengthened is set to 8 mm, the x-axis dimension L**2** of the channel-upstream-side adjacent portion and the x-axis dimension L**3** of the channel-downstream-side adjacent portion are set to 2 mm, and y-axis dimensions of the above position and portions are set to 8 mm in the direction into the page of FIGS. **4** and **5**. Therefore, the position **81** where the magnetic field is desired to be strengthened is square with 8 mm, and the channel-upstream-side adjacent portion **82** and the channel-downstream-side adjacent portion **83** are rectangular with an x-axis dimension of 2 mm and a y-axis dimension of 8 mm.

[0078] The magnetic field analysis was performed by a versatile magnetic field analysis method based on Maxwell's equation and Ampere's law. The magnetic field analysis was performed as follows on the basis of the analysis models of the electromagnet illustrated in FIGS. **4** and **5**. In a system having an air region of about five times longer than the long axis (sum of upper core length A**3**, coil length A**4**, and lower core length A**5**) of the electromagnet, an average magnetic c flux density in each of the following three locations included in the air region was obtained, the three locations being the position **81** (square with an x-axis dimension and a y-axis dimension of 8 mm, respectively) where the magnetic field is desired to be strengthened, and the channel-upstream-side adjacent portion **82** and the channel-downstream-side adjacent portion **83** (rectangular with an x-axis dimension of 2 mm and a y-axis dimension of 8 mm). As an analysis condition, the coil **20** is formed from copper and has 5000 turns. For comparison, the current value is set to 0.5 A in FIG. **4** and 1.0 A in FIG. **5** such that the magnetic flux densities in FIGS. **4**(*a*) and **5**(*a*) are almost the same. PB permalloy, which is a kind of general permalloy, is used for the core **21** and the fixed magnetic material **22**.

[0079] FIG. **6** is a diagram illustrating an analysis result of magnetic flux densities, and shows the magnitudes of the magnetic flux densities at three target locations for the analysis model according to the comparative example described with reference to FIG. **4** and the analysis model according to the first embodiment described with reference to FIG. **5**. When positional deviation does not occur (B**1**=0 mm), a large magnetic flux density is generated at the position **81** where the magnetic field is desired to be strengthened, and a small magnetic flux density is generated at the channel-upstream-side adjacent portion **82** and the channel-downstream-side adjacent portion **83**, regardless of the presence or absence of the fixed magnetic material. In this case, a strong magnetic field can be generated only on the reaction field electrode **14**, and this magnetic field is considered to be a magnetic field suitable for capturing the magnetic particles **13**. When positional deviation occurs (B**1**=1 mm or B**1**=2 mm), the magnetic flux density at the position **81** where the magnetic field is desired to be strengthened is high regardless of the presence or absence of the fixed magnetic material. In the comparative example, that is, in the model having no fixed magnetic material, the magnetic flux density increases particularly at the channel-upstream-side adjacent portion **82**. When a strong magnetic field is generated even in a place other than the region on the reaction field electrode **14**, the magnetic particles **13** are likely to be captured in a place that does not contribute to detection, and thus, such a magnetic field is considered to be an unsuitable magnetic field. On the other hand, in the present embodiment, that is, in the model having the fixed magnetic material, even if the position deviation occurs, the magnetic field smaller than that in the position **81** where the magnetic field is desired to be strengthened is maintained at the channel-upstream-side adjacent portion **82** and the channel-downstream-side adjacent portion **83**. Therefore, by using the fixed magnetic material **22**, a strong magnetic field limited in a region on the reaction field electrode **14** can be maintained, and a magnetic field structure in which the magnetic field around the reaction field electrode **14** is less likely to deviate can be provided.

[0080] Although the above analysis result shows only the effect in the x direction, the same effect can be expected also in the y direction and the z direction in the present embodiment that reduces imbalance in the magnetic field around the reaction field electrode **14** by guiding the magnetic field generated from the magnet to the reaction field electrode **14** with the fixed magnetic material **22**. That is, even if the positional deviation of the magnet is caused by displacement in any direction in the xyz-space, inclination, or rotation, the magnetic field can be induced to an appropriate position in the space around the flow cell to reduce imbalance in the magnetic field by adjusting the position, size, shape, number, and the like of the fixed magnetic material **22**. As a result, it is possible to provide a sample analyzer that is less likely to cause positional deviation of the magnetic field at a predetermined position in a detection channel and that enables highly accurate analysis.

Second Embodiment

[0081] The second embodiment will be described with reference to FIGS. **7** and **8**. In the following embodiments, the description of configurations and effects similar to those of the first embodiment will not be repeated.

[0082] FIG. **7** illustrates an analysis model according to the second embodiment in which a fixed magnetic material and a core are in contact with each other.

[0083] As illustrated in FIG. **7**, a fixed magnetic material **22** according to the present embodiment is not only exposed from the bottom surface of a flow cell but also in contact with a core **21** of a magnetic field generation source. Therefore, it is possible to further reduce the magnetic flux leaking from the magnetic field generation source into the air, and to further suppress a decrease in the magnetic field on a reaction field electrode **14**.

[0084] FIG. **7** illustrates a state in which a coil **20** and the core **21**, which are not fixed to the flow cell, of a magnetic field applying unit including the coil **20**, the core **21**, and the fixed magnetic material **22** deviate. A position **81** where the magnetic field is desired to be strengthened is indicated at a spatial position that is supposed to be a position on the reaction field electrode **14**, and a channel-upstream-side adjacent portion **82** and a channel-downstream-side adjacent portion are adjacent to the position **81** are indicated. Regarding the shape and dimension of the analysis model, the position and dimension of the core in the horizontal direction is represented by A**1**, the position and dimension of the core in the vertical direction is represented by A**2**, the upper core length is represented by A**3**, the coil length is represented by A**4**, the lower core length is represented by A**5**, the coil diameter is represented by A**6**, the core diameter is represented by A**7**, and the length of the fixed magnetic material is represented by A**9**. Further, the positional deviation dimension is represented by B**1**, the x-axis dimension of the position where the magnetic field is desired to be strengthened is represented by L**1**, the x-axis dimension of the channel-upstream-side adjacent portion is represented by L**2**, and the x-axis dimension of the channel-downstream-side adjacent portion is represented by L**3**.

[0085] In FIG. **7**, the dimensions are set as described below for comparison with FIG. **4** (analysis model without having a fixed magnetic material). That is, the position and dimension A**1** of the core in the horizontal direction is set to 0.5 mm, the position and dimension A**2** of the core in the vertical direction is set to 0.5 mm, the upper core length A**3** is set to 3 mm, the coil length A**4** is set to 60 mm, the lower core length A**5** is set to 5 mm, the coil diameter A**6** is set to 17 mm, the core diameter A**7** is set to 7 mm, the positional deviation dimension B**1** is set to 0 to 2 mm, the length of the fixed magnetic material A**9** is set to 2 mm, the x-axis dimension L**1** of the position where the magnetic field is desired to be strengthened is set to 8 mm, and the x-axis dimension L**2** of the channel-upstream-side adjacent position and the x-axis dimension L**3** of the channel-downstream-side adjacent position are set to 2 mm (the position **81** where the magnetic field is desired to be strengthened is square with 8 mm, and the channel-upstream-side adjacent portion **82** and the channel-downstream-side adjacent portion **83** are rectangular with an x-axis dimension of 2 mm and a y-axis dimension of 8 mm). In addition, in FIG. **7**, the core **21** and the fixed magnetic

material **22** are arranged without a gap, and thus, the gap A**8** between the fixed magnetic material and the core is 0 mm, and the description thereof is omitted.
[0086] The method for analyzing the magnetic field is similar to that in the first embodiment. Among various analysis conditions, the current value is set to 0.5 A that is the same as the current value in FIG. **4** in the present embodiment in FIG. **7**. The other analysis conditions are similar to those in the first embodiment.
[0087] FIG. **8** is a diagram illustrating an analysis result of magnetic flux densities, and shows the magnitudes of the magnetic flux densities at three target locations for the analysis model according to the comparative example described with reference to FIG. **4** and the analysis model according to the second embodiment described with reference to FIG. **7**. When positional deviation does not occur (B**1**=0 mm), the core **21** and the fixed magnetic material **22** in FIG. **7** are adjacent to each other without deviation, so that the structure of the analysis model is the same as that in FIG. **4**. Therefore, plots of the model having the fixed magnetic material are not illustrated.
[0088] According to FIG. **8**, when positional deviation occurs (B**1**=1 mm or B**1**=2 mm), the magnetic flux density at the channel-upstream-side adjacent portion **82** increases in the comparative example, that is, in the model having no fixed magnetic material, whereas the magnetic flux density is kept small in the present embodiment, that is, in the model having the fixed magnetic material. Therefore, by using the fixed magnetic material **22** according to the present embodiment, a magnetic field structure in which the magnetic field around the reaction field electrode **14** is less likely to deviate can be provided.
[0089] Furthermore, in the present embodiment, the gap A**8** between the fixed magnetic material and the core is eliminated (or reduced), whereby it is possible to reduce a magnetic flux leaking from the gap into the air. As a result, it is possible to suppress a decrease in the magnetic field on the reaction field electrode **14** in addition to the effect that the positional deviation of the magnetic field around the reaction field electrode **14** is less likely to occur. Accordingly, in the present embodiment, it is not necessary to increase the applied voltage (current) as in the first embodiment in FIG. **5**, and the positional deviation of the magnetic field around the reaction field electrode **14** is less likely to occur. Consequently, it is possible to ease manufacture and operation conditions and save consumption energy. For example, it is possible to reduce the turns of the coil **20**, operate the coil **20** at low voltage (low current), or employ a material having a low magnetic susceptibility to the core **21** and the fixed magnetic material **22**.
Third Embodiment
[0090] The third embodiment will be described with reference to FIGS. **9** to **12**.
[0091] FIG. **9** illustrates an analysis model according to the third embodiment in which the end face of a fixed magnetic material on the channel side has a smaller area. As illustrated in FIG. **9**, in the fixed magnetic material **22** according to the present embodiment, the cross-sectional area on the reaction field electrode side is smaller than the cross-sectional area on the magnetic field generation source side. For this reason, in the magnetic field generated by the magnetic field generation source, the density of the magnetic flux increases with nearness to the channel in the fixed magnetic material **22**, and the force for capturing magnetic particles **13** increases.
[0092] FIG. **9** illustrates a state in which a coil **20** and a core **21**, which are the magnetic field generation source, of a magnetic field applying unit including the coil **20**, the core **21**, and the fixed magnetic material **22** deviate. The fixed magnetic material **22** has a trapezoidal shape in an xz cross section in which the cross section at an end on the reaction field electrode **14** side (upper side) has a circular shape having a diameter smaller than that of the cross section at an end on the coil **20** side (lower side). A position **81** where the magnetic field is desired to be strengthened is indicated at a spatial position that is supposed to be a position on the reaction field electrode **14**, and a channel-upstream-side adjacent portion **82** and a channel-downstream-side adjacent portion **83** which are adjacent to the position **81** are indicated. Regarding the shape and dimension of the analysis model, the position and dimension of the core in the horizontal direction is represented by A**1**, the position

and dimension of the core in the vertical direction is represented by A**2**, the upper core length is represented by A**3**, the coil length is represented by A**4**, the lower core length is represented by A**5**, the coil diameter is represented by A**6**, the core diameter is represented by A**7**, the gap between the fixed magnetic material and the core is represented by A**8**, the length of the fixed magnetic material is represented by A**9**, the diameter of the upper surface of the fixed magnetic material is represented by A**10**, and the lateral dimension of the fixed magnetic material **1** is represented by A**11**. Further, the positional deviation dimension is represented by B**1**, the x-axis dimension of the position where the magnetic field is desired to be strengthened is represented by L**1**, the x-axis dimension of the channel-upstream-side adjacent portion is represented by L**2**, and the x-axis dimension of the channel-downstream-side adjacent portion is represented by L**3**.

[0093] In FIG. **9**, the dimensions are set as described below for comparison with FIG. **4** (analysis model without having a fixed magnetic material). That is, the position and dimension A**1** of the core in the horizontal direction is set to 0.5 mm, the position and dimension A**2** of the core in the vertical direction is set to 0.5 mm, the upper core length A**3** is set to 3 mm, the coil length A**4** is set to 60 mm, the lower core length A**5** is set to 5 mm, the coil diameter A**6** is set to 17 mm, the core diameter A**7** is set to 7 mm, the positional deviation dimension B**1** is set to 0 to 2 mm, the gap A**8** between the fixed magnetic material and the core is set to 0.5 mm, the length of the fixed magnetic material A**9** is set to 2 mm, the diameter A**10** of the upper surface of the fixed magnetic material is set to 5 mm, the lateral dimension A**11** of the fixed magnetic material is set to 1 mm, the x-axis dimension L**1** of the position where the magnetic field is desired to be strengthened is set to 8 mm, and the x-axis dimension L**2** of the channel-upstream-side adjacent position and the x-axis dimension L**3** of the channel-downstream-side adjacent position are set to 2 mm (the position **81** where the magnetic field is desired to be strengthened is square with 8 mm, and the channel-upstream-side adjacent portion **82** and the channel-downstream-side adjacent portion **83** are rectangular with an x-axis dimension of 2 mm and a y-axis dimension of 8 mm).

[0094] The method for analyzing the magnetic field is similar to that in the first embodiment. Among various analysis conditions, the current value is set to 1.0 A that is the same as the current value in FIG. **5** in the present embodiment in FIG. **9**. The other analysis conditions are similar to those in the first embodiment.

[0095] FIG. **10** is a diagram illustrating an analysis result of magnetic flux densities, and shows the magnitudes of the magnetic flux densities at three target locations for the analysis model according to the comparative example described with reference to FIG. **4** and the analysis model according to the third embodiment described with reference to FIG. **9**. When positional deviation occurs (B**1**=1 mm or B**1**=2 mm), the magnetic flux density at the channel-upstream-side adjacent portion **82** increases in the comparative example, that is, in the model having no fixed magnetic material, whereas the magnetic field is kept small in the present embodiment, that is, in the model having the fixed magnetic material. Therefore, by using the fixed magnetic material **22** according to the present embodiment, a magnetic field structure in which the magnetic field around the reaction field electrode **14** is less likely to deviate despite an occurrence of positional deviation of the magnetic field generation source can be provided.

[0096] Note that various modifications are conceivable for the shape of the fixed magnetic material **22**. Here, a plurality of representative shapes will be given as the shape of the fixed magnetic material **22**, and individual effects obtained by each shape will be described. FIG. **11** is a diagram illustrating a plurality of modifications regarding the shape of the fixed magnetic material.

[0097] FIGS. **11**(*a*) and (*b*) illustrate an example of the fixed magnetic material **22** having a cylindrical shape and an example of the fixed magnetic material **22** having a prismatic shape. The end face of the fixed magnetic material **22** on the reaction field electrode **14** side has a shape and size corresponding to the shape and size of the reaction field electrode **14**, whereby the magnetic field on the reaction field electrode **14** can be efficiently increased. For example, in a case where the reaction field electrode **14** is square, a prismatic fixed magnetic material **22** having a square end face on the reaction field electrode **14** side is used, and in a case where the reaction field electrode **14** is circular, a cylindrical fixed magnetic material **22** having a circular end face on the reaction field electrode **14** side is used. Note that the end face of the fixed magnetic material **22** on the magnetic field generation source side may be formed to have a shape and size corresponding to the shape and size of the core **21** of the magnetic field generation source to reduce imbalance in the magnetic field.

[0098] FIGS. **11**(*c*), (*d*), (*e*), and (*f*) illustrate examples in which the cross-sectional area at an end on the channel side (reaction field electrode **14** side) of the fixed magnetic material **22** is smaller than the maximum cross-sectional area of the fixed magnetic material **22**. When the fixed magnetic material **22** induces a magnetic field, a magnetic flux passes from any one of the faces to the opposite face. For example, in the fixed magnetic material as illustrated in each of FIGS. **11**(*c*), (*d*), (*e*), and (*f*), the magnetic flux entering the fixed magnetic material **22** from the face having a large cross-sectional area on the lower side in the z axis direction is emitted from the face having a small cross-sectional area on the upper side in the z axis direction, so that the density of the magnetic flux can be increased and a strong magnetic field can be generated in a limited range.

[0099] In addition, a large amount of magnetic flux entering the fixed magnetic material **22** from the core **21** via the air region is emitted from a sharp corner of the fixed magnetic material **22** to the air region. Therefore, the magnetic flux can be emitted into the air region from the corner on the side surface to reduce the magnetic flux not contributing to an increase in the magnetic field on the reaction field electrode **14** by using, for example, a shape in which an angle C**1** on the side surface of the fixed magnetic material **22** is less than 90 degrees, more preferably 45 degrees or less, and still more preferably 30 degrees or less, as illustrated in FIG. **11**(*d*). As a method for reducing sharp angles, two or more corners are formed on the side surface of the fixed magnetic material **22**, and angles C**1** and C**2** on the side surface are set to be less than 90 degrees, more preferably 45 degrees or less, and still more preferably 30 degrees or less as illustrated in FIG. **11**(*e*), for example. With this configuration, a similar effect can be expected. Furthermore, this effect is significant in a shape having no corner on the side surface, and can be further enhanced, for example, in a shape in which the side surface has a three-dimensional curved surface as illustrated in FIG. **11**(*f*).

[0100] FIGS. **11**(*g*), (*h*), (*i*), (*j*), and (*l*) illustrate examples in which the fixed magnetic material **22** has an uneven shape or hole on at least one end face of the fixed magnetic material **22**.

[0101] By forming the upper end face of the fixed magnetic material **22** to have an uneven shape as illustrated in FIGS. **11**(*g*), (*h*), and (*i*), it is possible to evenly provide a portion where a large amount of magnetic flux is emitted in the surface of the reaction field electrode **14** facing the fixed magnetic material by utilizing the fact that a large amount of magnetic flux entering the fixed magnetic material **22** is emitted from the corner at the upper end face to the air region. Thus, it is possible to reduce local imbalance in the magnetic field on the reaction field electrode **14** and to achieve uniform capturing of the magnetic particles **13** suitable for the detection of emitted light.

[0102] FIG. **11**(*j*) illustrates an example in which the upper end face of the fixed magnetic material **22** has an uneven shape asymmetric on the upstream side and the downstream side of the channel **10** in the liquid feeding direction. In the sample analyzer, when the magnetic particles **13** are captured from a fluid, the capture distribution of the magnetic particles **13** on the reaction field electrode **14** may change depending on the flow velocity and the strength of the magnetic field. For example, under a condition where the flow is relatively slow, the magnetic particles **13** are likely to be captured on the upstream (−x) side of the reaction field electrode **14**. In this case, in order to obtain the capture distribution of the magnetic particles **13** suitable for photodetection, the distance to the reaction field electrode **14** is increased on the upstream side of the fixed magnetic material **22**, and the distance to the reaction field electrode **14** is decreased on the downstream (+x) side as illustrated in FIG. **11**(*j*). With this configuration, the magnetic field is controlled so as to be weak on the upstream side of the reaction field electrode **14** and strong on the downstream side.

[0103] Thus, the capture distribution can be optimized so as to eliminate non-uniformity in the capture distribution of the magnetic particles **13** due to a flow field.

[0104] As the shape of the fixed magnetic material **22** having the same effect, for example, a shape in which the length of the side surface of the fixed magnetic material **22** varies depending on the location as illustrated in FIG. **11**(*k*), and a shape in which the side surface of the fixed magnetic material **22** in a specific direction is cut off as illustrated in FIG. **11**(*l*) are also effective. In FIG. **11**(*k*), the magnetic flux passes asymmetrically on the upstream side and the downstream side of the channel **10** on the surface of the fixed magnetic material on which the magnetic flux is incident or the surface of the fixed magnetic material **22** from which the magnetic flux is emitted. With this configuration, the capture distribution can be optimized so as to eliminate non-uniformity in the capture distribution of the magnetic particles **13** due to the flow field. In addition, in the structure illustrated in FIG. **11**(*l*), the side surface of the fixed magnetic material **22** is cut in a specific direction, and further, an uneven shape is formed in the end face. With this structure, it is possible to reduce local imbalance in the magnetic field on the reaction field electrode **14** in addition to the asymmetric generation of the magnetic field on the upstream side and the downstream side of the channel **10**.

[0105] FIG. **12** is a cross-sectional view illustrating a distribution of a magnetic flux density in each of representative shape examples of the fixed magnetic material.

[0106] FIGS. **12**(*a*), (*b*), (*c*), and (*d*) respectively illustrate cases where the fixed magnetic material has: a cylindrical shape; a shape in which the cross-sectional area of the upper end part is smaller; a shape in which the upper end face has an uneven shape; and a shape in which the upper end face has an uneven shape that is asymmetrical, and these shapes correspond to the shapes illustrated in FIGS. **11**(*a*), (*c*), (*g*), and (*j*), respectively.

[0107] FIGS. **12**(*a*) and (*b*) illustrate the analysis cases same as that for the case of the positional deviation of 0 mm (B**1**=0 mm) in FIG. **5**(*a*) and FIG. **9**, and the dimensions are set as described below. That is, the position and dimension A**1** of the core in the horizontal direction is set to 0.5 mm, the position and dimension A**2** of the core in the vertical direction is set to 0.5 mm, the upper core length A**3** is set to 3 mm, the coil length A**4** is set to 60 mm, the lower core length A**5** is set to 5 mm, the coil diameter A**6** is set to 17 mm, the core diameter A**7** is set to 7 mm, the positional deviation dimension B**1** is set to 0 to 2 mm, the gap A**8** between the fixed magnetic material and the core is set to 0.5 mm, the length of the fixed magnetic material A**9** is set to 2 mm, the diameter A**10** of the upper surface of the fixed magnetic material is set to 5 mm, and the lateral dimension A**11** of the fixed magnetic material is set to 1 mm.

[0108] In FIG. **12**(*c*), the length of the fixed magnetic material A**9** is set to 1.7 mm, the diameter A**10** of the upper surface of the fixed magnetic material is set to 5 mm, the lateral dimension A**11** of the fixed magnetic material is set to 1 mm, the dimension A**12** of a groove of the fixed magnetic material is set to 0.3 mm, and the other dimensions are the same as those in FIGS. **12**(*a*) and (*b*).

[0109] In FIG. **12**(*d*), the length of the fixed magnetic material A**9** is set to 1.7 mm, the diameter A**10** of the upper surface of the fixed magnetic material is set to 3.5 mm, the lateral dimension A**11** of the fixed magnetic material is set to 3.5 mm, the dimension A**12** of the groove of the fixed magnetic material is set to 0.3 mm, and the other dimensions are the same as those in FIGS. **12**(*a*) and (*b*).

[0110] The method for analyzing the magnetic field is similar to that in the first embodiment. Among various analysis conditions, the current value is set to 1.0 A that is the same as the current value in FIG. **5** in the present embodiment in FIG. **12**. The other analysis conditions are similar to those in the first embodiment.

[0111] The effects of the shape illustrated in FIG. **12**(*b*) in which the cross-sectional area of the upper end face is smaller, the shape illustrated in FIG. **12**(*c*) in which the upper end face has an uneven shape, and the shape illustrated in FIG. **12**(*d*) in which the upper end face has an uneven shape that is asymmetrical will be described in comparison with the cylindrical shape illustrated in FIG. **12**(*a*).

[0112] Regarding the shape illustrated in FIG. **12**(*b*) in which the cross-sectional area of the upper end face is smaller, the density of the magnetic flux generated from the central part of the upper end face of the fixed magnetic material **22** is larger than that in the fixed magnetic material having the cylindrical shape illustrated in FIG. **12**(*a*), and the magnetic field is locally concentrated. As a result, the magnetic flux density limited on the reaction field electrode **14** can be increased. The effect of the shape illustrated in FIG. **12**(*c*) in which the upper end face has an uneven shape is considered. The magnetic flux density generated from the upper part of the fixed magnetic material **22** is concentrated on the corners in the cylindrical shape illustrated in FIG. **12**(*a*), whereas in the shape illustrated in FIG. **12**(*c*) in which the upper end face has an uneven shape, the concentration of the magnetic flux density on the corners is reduced, and the magnetic flux density tends to spread all over the entire upper surface of the fixed magnetic material **22**. Thus, it is possible to reduce local imbalance in the magnetic field on the surface of the reaction field electrode **14** and to achieve uniform capturing of the magnetic particles **13** suitable for the detection of emitted light. Regarding the shape illustrated in FIG. **12**(*d*) in which the upper end face has an uneven shape that is asymmetrical, the magnetic flux density generated from the upper part of the fixed magnetic material **22** varies in size between on the −x side and on the +x side. Thus, under a condition where, for example, the flow is relatively slow, the magnetic field on the downstream side of the reaction field electrode **14** is controlled to be greater than that on the upstream side, whereby it is possible to perform control so as to eliminate the non-uniformity in the capture distribution of the magnetic particles **13**.

[0113] In addition, as can be seen from FIG. **12**, in all shapes, the magnetic flux density is large from the corner of the upper end face of the fixed magnetic material **22** to a certain region. Therefore, even if the area of the reaction field electrode **14** located above the fixed magnetic material **22** is larger than the cross-sectional area of the upper end face of the fixed magnetic material **22** by a certain degree, it is possible to induce a large amount of magnetic flux over the entire region on the reaction field electrode **14** by using the magnetic flux reaching the reaction field electrode **14** from the fixed magnetic material **22** via the air region.

Fourth Embodiment

[0114] The fourth embodiment will be described with reference to FIGS. **13**, **14**, and **15**.

[0115] FIG. **13** is a diagram illustrating configurations of a magnetic field applying unit and a flow cell according to the fourth embodiment, and illustrates a cross section on a zx plane when a coordinate system is used in which a traveling direction of flow in the channel **10** is an x axis, a horizontal direction of the cross section perpendicular to the flow is a y axis, and the vertical direction thereof is a z axis.

[0116] In the present embodiment, a fixed magnetic material **22** is provided on a channel top wall **11**, and the distance between a channel **10** and the fixed magnetic material **22** is minimum on the top surface side of the channel **10**. The present embodiment can also provide an effect that positional deviation of a magnetic field around a reaction field electrode **14** is less likely to occur because of the fixed magnetic material **22** being integrally formed with a flow cell. Although not illustrated in FIG. **13**, a counter electrode **15** can be installed above the channel **10** without interfering with the fixed magnetic material **22** by, for example, arranging a plurality of linear electrodes in the x direction or the y direction in the channel **10**.

[0117] Regarding the effect of suppressing the positional deviation of the magnetic field according to the present embodiment, the results confirmed by magnetic field analysis will be described with reference to FIGS. **14** and **15**.

[0118] FIG. **14** illustrates an analysis model according to the fourth embodiment in which the fixed magnetic material is provided on the channel top wall. In FIG. **14**, a position **81** where the magnetic field is desired to be strengthened is indicated, assuming that the reaction field electrode **14** is present in a space between the core **21** and the fixed magnetic material **22**. Further, at adjacent positions, a channel-upstream-side adjacent portion **82** and a channel-downstream-side adjacent portion **83** are indicated. FIG. **14** illustrates a state in which the coil **20** and the core **21** deviate with a positional deviation dimension of B**1**. Regarding the shape and dimension of the analysis model, the position and dimension of the core in the horizontal direction is represented by A**1**, the position and dimension of the core in the vertical direction is represented by A**2**, the upper core length is represented by A**3**, the coil length is represented by A**4**, the lower core length is represented by A**5**, the coil diameter is represented by A**6**, the core diameter is represented by A**7**, the gap between the fixed magnetic material and the core is represented by A**8**, and the length of the fixed magnetic material is represented by A**9**. Further, the positional deviation dimension is represented by B**1**, the x-axis dimension of the position where the magnetic field is desired to be strengthened is represented by L**1**, the x-axis dimension of the channel-upstream-side adjacent portion is represented by L**2**, and the x-axis dimension of the channel-downstream-side adjacent portion is represented by L**3**.

[0119] In FIG. **14**, the gap A**8** between the fixed magnetic material and the core is 3 mm, and the position **81** where the magnetic field is desired to be strengthened is set at the center thereof, and thus, the position and dimension A**2** of the core in the vertical direction is set to 1.5 mm. In FIG. **15**, an analysis result of a model in which the position **81** where the magnetic field is desired to be strengthened is set at a location corresponding to the location in FIG. **4** (analysis model without having a fixed magnetic material) with the position and dimension A**2** of the core in the vertical direction being set as 1.5 mm is used for comparison. In FIG. **14**, the length of the fixed magnetic material A**9** is set to 5 mm, and the other dimensions are the same as those in FIG. **4**.

[0120] The method for analyzing the magnetic field is similar to that in the first embodiment, and the current value is set to 0.5 A in FIG. **4** and set to 0.35 A in FIG. **14** so that the magnetic flux densities in FIGS. **4**(*a*) and **14** are almost the same. The other analysis conditions are similar to those in the first embodiment.

[0121] FIG. **15** is a diagram illustrating an analysis result of magnetic flux densities, and shows the magnitudes of the magnetic flux densities at three target locations for the analysis model according to the comparative example described with reference to FIG. **4** and the analysis model according to the fourth embodiment described with reference to FIG. **14**. When positional deviation does not occur (B**1**=0 mm), the magnetic flux density at the position **81** where the magnetic field is desired to be strengthened is substantially equal between the model without having a fixed magnetic material, that is, the comparative example, and the model having the fixed magnetic material provided on the channel top wall, that is, the present embodiment. However, the magnetic flux density at the channel-upstream-side adjacent portion **82** and at the channel-downstream-side adjacent portion **83** in the present embodiment is smaller than that in the comparative example. Therefore, in the present embodiment, a strong magnetic field can be limited only on the reaction field electrode **14**.

[0122] When positional deviation occurs (B**1**=1 mm or B**1**=2 mm), a difference between the magnetic flux density at the position **81** where the magnetic field is desired to be strengthened and the magnetic flux density at the channel-upstream-side adjacent portion **82** and a difference between the magnetic flux density at the position **81** where the magnetic field is desired to be strengthened and the magnetic flux density at the channel-downstream-side adjacent portion **83** are greater in the present embodiment having the fixed magnetic material provided on the channel top wall than in the comparative example having no fixed magnetic material. Therefore, the present embodiment is more effective in generating a magnetic field limited on the reaction field electrode **14**, and can ensure a magnetic field suitable for capturing the magnetic particles **13**. The present embodiment can also provide a magnetic field structure in which the magnetic field around the reaction field electrode **14** is less likely to deviate regardless of an occurrence of positional deviation of the magnetic field generation source.

[0123] In a case where the fixed magnetic material **22** is provided on the channel top wall, the magnetic flux easily passes through the space between the core **21** and the fixed magnetic material

22, so that a larger magnetic flux density is easily obtained than in a case where the fixed magnetic material is not provided.

[0124] This is advantageous for capturing the magnetic particles **13**, and capturing of the magnetic particles suitable for photodetection can be achieved.

[0125] Alternatively, a load voltage (current) to the coil **20** necessary for obtaining the equivalent magnetic flux density can be reduced, and the operation with energy saving can be achieved.

[0126] In a case where the fixed magnetic material is disposed on the upper side as in the present embodiment, the fixed magnetic material **22** may interfere with an optical path when light emission in the flow cell is observed by the photodetector **23**. In that case, a hole is formed in the fixed magnetic material **22**, for example, as in the shape illustrated in FIG. **11**(*i*) or (*l*), by which the optical path can be ensured.

Fifth Embodiment

[0127] The fifth embodiment will be described with reference to FIG. **16**. FIG. **16** is a diagram illustrating a configuration of a magnetic field applying unit and a flow cell according to the fifth embodiment. When a coordinate system is used in which a traveling direction of flow in the channel **10** is an x axis, a horizontal direction of the cross section perpendicular to the flow is a y axis, and the vertical direction thereof is a z axis, FIG. **16**(*a*) illustrates a cross section on a zx plane, and FIG. **16**(*b*) illustrates a cross section on an xy plane.

[0128] In the present embodiment, a fixed magnetic material **22** is disposed on the side part of a channel **10**, that is, on a channel side wall **18**. Such an arrangement can also provide a magnetic field structure in which the positional deviation of the magnetic field around the reaction field electrode **14** is less likely to occur. When the fixed magnetic material **22** is provided on the channel side wall **18**, it may be provided on one or both of the channel side walls **18** facing each other.

Sixth Embodiment

[0129] The sixth embodiment will be described with reference to FIG. **17**. FIG. **17** is a diagram illustrating a configuration of a magnetic field applying unit and a flow cell according to the sixth embodiment. In the present embodiment, a plurality of the fixed magnetic materials **22** is provided. Such an arrangement can also provide a magnetic field structure in which the positional deviation of the magnetic field around the reaction field electrode **14** is less likely to occur.

[0130] Furthermore, the magnetic field on the reaction field electrode **14** can be appropriately controlled by using a plurality of fixed magnetic materials **22** which is different in size, shape, material, or the like as in the present embodiment. For example, the fixed magnetic material **22** having a small susceptibility magnetic or saturation magnetic flux density is disposed in the vicinity of the upstream side of the reaction field electrode **14**, and the fixed magnetic material **22** having a large magnetic susceptibility or saturation magnetic flux density is side of the disposed in the vicinity of the downstream reaction field electrode **14**, whereby the magnetic field can be asymmetrically controlled. With this configuration, non-uniformity in the capture distribution of the magnetic particles **13** due to the flow field can be eliminated. In addition, the magnetic field on the upstream side and on the downstream side of the reaction field electrode **14** can also be controlled using specifications or operating conditions of the coil **20** and the core **21** of the plurality of electromagnets. For example, a voltage (current) larger than that applied to the coil **20** of the electromagnet in the vicinity of the upstream side of the reaction field electrode **14** is applied to the coil **20** of the electromagnet in the vicinity of the downstream side of the reaction field electrode **14**, by which the magnetic field in the vicinity of the downstream side can be increased.

[0131] Therefore, it is not necessary to divide both the fixed magnetic material **22** and the coil **20** and the core **21** that constitute the magnetic field generation source into a plurality of parts, and only the fixed magnetic material **22** may be divided into multiple parts or only the magnetic field generation source may be divided into multiple parts. Note that, in a case where only one fixed magnetic material **22** is used, the fixed magnetic material **22** may have a shape as illustrated in FIG. **11**(*j*) or (*k*), for example.

Seventh Embodiment

[0132] The seventh embodiment will be described with reference to FIG. **18**. FIG. **18** is a diagram illustrating a configuration of a magnetic field applying unit and a flow cell according to the seventh embodiment. In the present embodiment, a fixed magnetic material is used without using a core, that is, a fixed magnetic material **22** integrated with a flow cell can be inserted into an internal space of a coil **20**. Therefore, the fixed magnetic material **22** according to the present embodiment has a function of generating a magnetic field in addition to a function of inducing a magnetic field. The present embodiment can also provide a magnetic field structure in which the positional deviation of the magnetic field around a reaction field electrode **14** is less likely to occur.

Eighth Embodiment

[0133] The eighth embodiment will be described with reference to FIG. **19**. FIG. **19** is a diagram illustrating configurations of a magnetic field applying unit and a flow cell according to the eighth embodiment. In the present embodiment, an electromagnet having a bent shape is used, both ends of a core **21** face a flow cell, and a fixed magnetic material **22** is provided to face both ends of the core **21**. This configuration can provide a magnetic field structure in which the positional deviation of the magnetic field around a reaction field electrode **14** is less likely to occur.

[0134] Furthermore, by using an electromagnet having a bent shape as in the present embodiment, it is possible to create a magnetic circuit with less air region around the flow cell, whereby the magnetic flux density generated from the end of the core **21** can be increased. Since the fixed magnetic material **22** faces both ends of the core **21**, a large magnetic flux density can be obtained on the reaction field electrode **14** via a large amount of magnetic flux. In the present embodiment, even when the reaction field electrode **14** is on the channel bottom wall **12**, the electromagnet is not limited to be placed below the flow cell. That is, an electromagnet having a bent shape may be disposed, for example, from below the flow cell to the side surface thereof, from one side surface to the opposing side surface, or from below to an area above the flow cell.

Ninth Embodiment

[0135] The ninth embodiment will be described with reference to FIG. **20**. FIG. **20** is a diagram illustrating configurations of a magnetic field applying unit and a flow cell according to the ninth embodiment. In the present embodiment, a permanent magnet **70** is used as a magnetic field generation source. Specifically, a movable arm **71** to which the permanent magnet **70** is fixed is rotated to bring the permanent magnet **70** close to or away from the flow cell to thereby increase or decrease the magnetic field on a reaction field electrode **14**.

[0136] FIG. **20**(*a*) illustrates a state in which the permanent magnet **70** is close to the flow cell, and this state is established when magnetic particles **13** are captured on the reaction field electrode **14**. On the other hand, FIG. **20**(*b*) illustrates a state in which the permanent magnet **70** is away from the flow cell, and this state is established when the magnetic particles **13** are removed from the reaction field electrode **14**.

[0137] In the present embodiment, the fixed magnetic material **22** is formed integral with the flow cell, and thus, a magnetic field structure in which positional deviation of a magnetic field around the reaction field electrode **14** is less likely to occur can be obtained. Note that the movable arm **71** in the present embodiment is not limited to a rotary motion mechanism with one supporting point, and regarding the number, position, and direction of supporting points during motion, any number of supporting points may be set based on any position and any plane in a three-dimensional space. In addition, as a motion mechanism using motions other than rotation, another mechanism using, for example, a motion on one axis using a rail or the like may be adopted.

[0138] The present invention is not limited to the above-described embodiments, and various modifications are possible. For example, the above-described embodiments have been described in detail for easy understanding of the present invention, and are not necessarily limited to those having all the described configurations. In addition, a part of the configuration of a certain embodiment can be replaced with or added to the configuration of another embodiment.

REFERENCE SIGNS LIST

[0139] **10** channel [0140] **11** channel top wall [0141] **12** channel bottom wall [0142] **13** magnetic particle [0143] **14** reaction field electrode [0144] **15** counter electrode [0145] **16**, **17** voltage applying unit [0146] **18** channel side wall [0147] **20** coil [0148] **21** core [0149] **22** fixed magnetic material [0150] **23** photodetector [0151] **30** sipper nozzle [0152] **31** arm [0153] **32**, **33**, **34** tube [0154] **35** pump [0155] **36**, **37** valve [0156] **40** suspension container [0157] **41** reaction unit [0158] **42** cleaning liquid container [0159] **43** buffer solution container [0160] **44** cleaning mechanism [0161] **45** waste container [0162] **50** controller [0163] **51**, **52**, **53**, **54**, **55***a*, **55***b*, **55***c*, **56***a*, **56***b*, **57** signal line [0164] **61** flow direction [0165] **70** permanent magnet [0166] **71** movable arm [0167] **81** position where magnetic field is desired to be strengthened [0168] **82** channel-upstream-side adjacent portion [0169] **83** channel-downstream-side adjacent portion

Claims

1.-**15**. (canceled)

16. A sample analyzer comprising: a channel that introduces a sample liquid containing a magnetic particle bound to a labeling substance; a liquid feeding unit that supplies and discharges the sample liquid into and from the channel; a magnetic field applying unit that applies a magnetic field for capturing the magnetic particle in the channel; and a detector that detects the labeling substance bound to the magnetic particle that has been captured, wherein the channel is provided with an electrode to which a voltage for causing the labeling substance to emit light is applied, and the magnetic field applying unit includes a magnetic field generation source and a magnetic material that induces a magnetic field from the magnetic field generation source to the electrode, the magnetic material being integrally formed with the channel.

17. The sample analyzer according to claim 16, wherein the magnetic field generation source is an electromagnet including a coil.

18. The sample analyzer according to claim 16, wherein the magnetic field generation source is a permanent magnet.

19. The sample analyzer according to claim 16, wherein the magnetic material is embedded in a wall of the channel.

20. The sample analyzer according to claim 16, wherein the magnetic material is exposed from the channel toward the magnetic field generation source.

21. The sample analyzer according to claim 20, wherein the magnetic material is in contact with the magnetic field generation source.

22. The sample analyzer according to claim 16, wherein the electrode includes a reaction field electrode provided at a bottom part of the channel and a counter electrode provided at an upper part of the channel, and the magnetic field generation source is located below the reaction field electrode.

23. The sample analyzer according to claim 22, wherein the magnetic material is provided on a bottom wall of the channel.

24. The sample analyzer according to claim 23, wherein the magnetic material has a shape in which an end face on a side of the reaction field electrode is along a shape of the reaction field electrode, or a shape in which an end face on a side of the magnetic field generation source is along a shape of the magnetic field generation source.

25. The sample analyzer according to claim 23, wherein the magnetic material has a smaller cross-sectional area on the side of the reaction field electrode than a cross-sectional area on the side of the magnetic field generation source.

26. The sample analyzer according to claim 23, wherein the magnetic material has an end face smaller than the reaction field electrode on a side of the reaction field electrode.

27. The sample analyzer according to claim 22, wherein the magnetic material is provided on a top wall of the channel.

28. The sample analyzer according to claim 16, wherein the magnetic material has an asymmetric shape on an upstream side and on a downstream side of the channel in a liquid feeding direction.

29. The sample analyzer according to claim 16, wherein different magnetic materials are provided on an upstream side and a downstream side of the channel in a liquid feeding direction.