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(54) Hose pump and device for analysing a chemical or biological sample

(57) Hose pump with a hose for taking up the fluid to be pumped and with a planetary gear rack having a ring gear, a sun gear and at least two planetary gears interposed between the ring gear and the sun gear, wherein at least one of the teeth of the planetary gear during one cycle of the planetary gear around the sun gear at least once engages with the hose to squeeze a portion of the hose.

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Description

[0001] The invention relates to a hose pump. The invention also relates to a device or a system having such a hose pump and, especially, to a device or system for analysing a chemical or biological sample, in particular a sample of biological origin, e.g. a biological sample comprising nucleic acids. The invention, furthermore, relates to the field of "lab-on-the-chip" technology suitable for "in-field" and "point-of-care" (POC) applications.

[0002] From WO 2010/003690 A1 a device for analysing a sample is known, said device comprising at least one depot chamber and at least one process chamber, is known, whereas the process chamber is integrated in at least one first support member and the depot chamber is integrated in at least a second support member, whereas the support members are arranged in that the process chamber is connectable with the depot chamber by a relative movement of the first and second support members with respect to each other. The device has a pump element for transferring the substances inside the device from one chamber to another, said pump element being integrated in one of the support members.

[0003] Highly sophisticated chemical, biochemical or molecular biology based analyses, such as nucleic acid testing, NAT, and in particular all modifications of polymerase chain reaction (PCR), become more and more attractive in medicine and health care as well as in nearly all fields of industry, including agriculture, biotechnology, chemical and environmental businesses. There is a great demand for analytical methods capable of satisfying the increasing requirements concerning, for instance, therapeutic outcome or planning and controlling of industrial manufacturing processes and costs.

[0004] Most of the state-of-the-art analytical systems are very complex, require handling of unstable reagents, expensive laboratory equipment, and highly trained personnel to conduct and interpret the testing. Hence, the analysis is usually neither time- nor cost-effective as it involves sending a specimen to a specialised laboratory with considerable delay in obtaining results. For this reason, in-field and point-of-care testing (POCT) have become particularly desirable as they significantly shorten sampling-to-result time. In clinical diagnostic, some asymptomatic patients are likely to become impatient with the testing process and fail to attend the follow up appointment, thus should be offered proper treatment or reassurance during a single visit. Furthermore, there is a prompt need for rapid, easy-to-perform tests for other in-field applications, e.g. forensic testing ("scene-of-crime", "point-of-arrest"), food testing (GMO detection, food fraud), defence (bio-thread detection), and many more.

[0005] Until now, lab-processed nucleic acid testing (NAT) has generally had much greater sensitivity than rapid POC tests, being usually based on pathogen immunodetection. Most of the NAT-based platforms and technologies currently under development do not provide an integrated solution for sample preparation, analysis, and data evaluation. An example of a successful platform is known from WO 2005/106040 A2. Said device, however, requires manual loading of reagents which can be inconvenient for the user and error-prone. Also the data evaluation requires operator intervention. It is, therefore, inappropriate for in-field testing. Further, the complex lab-in-a-box design of the device, which consists of several large injection moulded parts and further several mounting parts such as filters, screws, and nuts, etc., results in high costs for the disposable device.

[0006] For a device as known from WO 2010/003690 A1, especially if it is to be used as a disposable cartridge, a hose pump that can be produced in a cost efficient manner, but especially a hose pump that operates in a reliable manner, is beneficial.

[0007] Given this background, the problem to be solved by the invention is to propose a hose pump that can be produced in a cost efficient manner, but, especially, a hose pump that operates in a reliable manner is beneficial.

[0008] This problem is solved by the hose pump according to claim 1, the device according to claim 8 and/or the system according to claim 9. Preferred embodiments form part of the subordinate claims and the description following here after.

[0009] The invention is based on the general idea of using the planetary gear of a planetary gear rack as rollers for the hose pump. Planetary gears in planetary gear racks take up precisely definable positions within the ring gear during a circulation of the planetary gear around the sun gear. This allows the precise controlling of the amount of fluid being pumped by the hose pump. Additionally, planetary gear racks can be produced in a cost efficient manner, which allows for the hose pump as such to be produced in a cost-efficient manner.

[0010] The use of planetary gears of a planetary gear rack instead of passive rollers as they are being used in hose pumps of the prior art has the advantage that the circumferential speed of the planetary gear is exactly the same speed with which it travels along the hose, if the hose is arranged at a circumferential position of the planetary gear. This leads to the positive effect that the planetary gear does not induce a pulling force onto the hose. This leads to a more precise pumping action.

[0011] In a preferred embodiment, a portion of the hose is arranged in the form of a ring segment. In a preferred embodiment, the tooth of the planetary gear engages the hose in this hose portion. In an especially preferred embodiment, several teeth of the planetary gear are made to engage the hose in one moment of time. In a preferred embodiment, the planetary gear rolls along the hose portion. In a preferred embodiment of the embodiment, that has the planetary gear roll along the hose portion after the first tooth has engaged with the hose for the first time of this cycle until the last tooth disengages from the hose for this cycle at all other times of engagement of teeth of the planetary gear with the hose, at least one tooth of the planetary gear is in engagement with the hose at the same moment in time.

[0012] Although the planetary gear has a circumferential shape that is defined by the teeth, the planetary gear will act like a roller on the hose, the gap between the tips of the teeth being spanned by the hose. In a preferred embodiment, the tips of the teeth of a planetary gear are flattened. This, on the one hand, reduces the gap between the teeth, and, thus, what needs to be spanned by the hose. On the other hand, flattened teeth or teeth with a roof ridge with large internal ridge angle reduce the wear on the hose. Then again, the tips of the teeth can have an anti-slip effect to prevent the slipping of the planetary gear as it rolls along the hose.

[0013] In a preferred embodiment, the planetary gear rack has more than three planetary gears, especially preferred more than four planetary gears, and especially preferred more than five or equal to five planetary gears.

[0014] In a preferred embodiment, in all operational conditions of the hose pump at least one of the teeth of at least one of the planetary gear of the planetary gear rack is in engagement with the hose to squeeze a portion of the hose. This prevents the fluid in the hose from flowing backwards. As an alternative, it is feasible to have a valve downstream of the hose portion that the tooth of the planetary gear comes into engagement with. The valve would be opened as the tooth of the planetary gear comes into engagement with the hose and by squeezing the hose displaces fluid within the hose. Opening the valve would allow a portion of a fluid that is proportional to the portion of the fluid being displaced by the planetary gear engaging with the hose to flow past the valve. The valve would be closed to prevent backflow of the fluid as the tooth of the planetary gear comes into disengagement with the hose. If, however, as described above, the hose pump is designed in such a manner that at least one tooth of at least one of the planetary gears of the planetary gear rack is in engagement with the hose to squeeze a portion of the hose, in all operational conditions, such a valve can be done away with, because the tooth squeezing the hose portion can be used to prevent or reduce the back flow of the fluid.

[0015] With the hose pump according to the invention, at least one of the teeth of the planetary gear rack engages with the hose to squeeze a portion of the hose. In a preferred embodiment, the term "squeeze" is to be understood to mean that the hose portion is squeezed in such a manner that the channel within the hose is closed for a portion of its extent. Closing the channel within the hose fully prevents fluid flow past the portion that is being squeezed. The advantages of the invention (possibly to a lesser extent) will, however, also be reached if in an alternative embodiment the term "squeeze" is understood in such a sense that the engagement of the tooth with the hose closes the channel within the hose only partially. The remaining gap theoretically allows for a backflow of fluid past the portion of the hose being squeezed. It is, however, to be expected that the flow resistance in this portion of the hose is substantially increased, which reduces the amount of fluid that flow back past the portion of the hose being squeezed.

[0016] In a preferred embodiment, the hose pump has a support surface; the portion of the hose being squeezed between the tooth of the planetary gear and the support surface. In a preferred embodiment, the support surface has a bent shape. In a preferred embodiment, the hose is in contact with the bent support surface such that the portion of the hose that is in contact with the support surface takes up the shape of a ring segment. This provides a good design that allows the planetary gear of the planetary gear rack to roll along this hose section while squeezing a portion of the hose against a portion of the support surface.

[0017] In a preferred embodiment the ring gear of the planetary gear rack is a ring segment, whereby the ring gear instead of a further ring segment that would complete the ring gear to a ring has an opening, a portion of the hose being arranged inside this opening. This design allows for an easy way to bring the planetary gear of the planetary gear rack into engagement with the hose in order to squeeze a portion of the hose.

[0018] In a preferred embodiment, the ring segment of the ring gear spans over more than 180 °. It is to be expected that the stability and precision of the movement of the planetary gear that engages the hose portion is also affected by the stability of a cage of the planetary gear rack that holds the planetary gear. The stability of the cage of the planetary gear rack can be increased in an embodiment, where at least two planetary gears are provided as part of the planetary gear rack and at least one of the planetary gears is in engagement with the ring gear. This can be achieved by having the ring gear span over more than 180 °.

[0019] In a preferred embodiment, the opening of the ring gear spans over more than an enclosure angle, the enclosure angle being calculated by the formula:

$$\text{Enclosure angle} = 360\,° / \text{number of planetary gears of the planetary gear rack.}$$

[0020] For two planetary gears, the enclosure angle would thus be 180 ° and the opening of the ring segment of the ring gear would span more than 180 °. For three planetary gears of a planetary gear rack, the enclosure angle would be 120 ° and the opening of the ring gear of such an embodiment would span, preferably, over more than 120 °. In a preferred embodiment of the embodiment with a ring gear that has an opening, a portion of the hose is arranged inside the opening with the shape of a ring segment that spans over at least 40 %, preferably over at least 50 %, especially preferred over 75 % of the angle that the ring gear has an opening rather than a ring segment. The more opening is taken up by the portion of the hose, the more the rotational movement of the planetary gear around the sun gear can be used for pushing the fluid inside the channel of the hose along the channel.

[0021] In a preferred embodiment, the size of the opening in the embodiment where the ring gear has an opening correlates to the number of planetary gears of the planetary gear rack in such a manner that for the majority of the time only one planetary gear of the planetary gear rack is in engagement with a portion of the hose. Preferably, only as the one planetary gear comes out of engagement with the hose, the next planetary gear comes into engagement with the hose in order to prevent or reduce the flow back of fluid. This can be achieved if the angle over which the portion of the hose spans in the shape of a ring segment is equal to or a little bit larger than the enclosure angle. In such an embodiment, the segment of the ring would need to span over less than (360° minus the enclosure angle).

[0022] In a preferred embodiment, the planetary gear in the direction of its rotational axis extends over the ring gear, whereby the portion of the planetary gear that extends over the ring gear engages into the hose to squeeze a portion of the hose. In such an embodiment, the hose can be arranged next to the ring gear, and the ring gear can be designed to be a complete ring. This would allow for a planetary gear of the planetary gear rack to be in engagement with a portion of the hose while the planetary gear at the same time is in engagement with the ring gear. This can further stabilize the positioning of the planetary gear as it is in engagement with the hose.

[0023] In a preferred embodiment, a portion of the hose is arranged in the shape of a ring segment with the same radius as the ring gear, and is arranged next to the ring gear such that the portion of the planetary gear that extends over the ring gear comes into contact with the portion of the hose.

[0024] In a preferred embodiment, a position sensor is arranged at the planetary gear or at the cage to determine the rotational position of the planetary gear in the planetary gear rack. Knowledge about the rotational position of the planetary gear within the planetary gear rack allows for a better control of the pumping action of the hose pump.

[0025] The device according to the invention has at least one depot chamber and at least one process chamber, whereas the process chamber is integrated in at least one first support member and the depot chamber is integrated in at least a second support member, whereas the support members are arranged in that the process chamber is connectable with the depot chamber by a relative movement of the first and second support members with respect to each other, the device further comprising a pump element for transferring the substances inside the device from one chamber to another. The device has as pump element a hose pump according to the invention.

[0026] As system according to the invention has a hose pump according to the invention or a device according to the invention and a base station, said base station comprising at least a pump drive which acts on the hose pump to drive the planetary gear around the sun gear, for example by driving the sun gear. Alternatively, the cage holding the planetary gear could be driven.

[0027] In a preferred embodiment, in the system according to the invention the hose pump or the device is detachably connected to the base station. This allows, for example for the drive of the planetary gear to be made part of the base. This implies that the term "hose pump" according to the invention is to be understood in such a sense that it also refers to embodiments without a drive for the planetary gear.

[0028] In a preferred embodiment, the planetary gear rack has more than two planetary gears. Preferably, the planetary gear rack has six or less than six planetary gears.

[0029] The device for analysing a sample according to the invention provides a simple and incomplex design, and in particular a design which can be inexpensively produced. Thus, the invention also provides a device which suitably allows the use as a "disposable", i.e. a lab-on-a-chip which is disposed after use. Accordingly the device of the invention is particularly suitable for in-field and point-of-care settings. Further, by integrating the pump element into the device itself, all elements which will contact the substances during analysis are combined in a - preferably disposable - unit, which allows for the creation of a closed fluidic system, which helps preventing any contamination of the substances or the interior of the device itself. Such contamination may occur when the device would have to be connected to an "exterior" pump. Advantageously, the chamber of the device can be pre-filled with reagents adapted to perform a distinct analysis. Therewith, the device can be used as a "ready-to-use" format of a lab on a chip.

[0030] The sample analysed in the device of the invention can be of any origin or nature, for example of biological, natural, synthetic or semi-synthetic origin. The invention, thus, is not limited to any specific sample origin.

[0031] Preferably, an elastic hose may be provided as part of the pump element. The elastic hose may be connected to the chambers by respective conduits, which are integrated into the support members. A pumping pressure may be created inside the elastic hose by locally deforming and thereby reversibly sealing it, for example by means of a roller element, which is moved along the length of the elastic hose This creates a positive pressure inside the elastic hose on the side of the roller element which faces in the direction of movement. Consequently, a negative pressure is created on the opposite side inside the elastic hose.

[0032] The term "elastic hose" according to the invention may cover all elements, which define an interior space and have an elastic shell surrounding said interior space and further at least one inlet and one outlet. An elastic hose according to the invention does not necessarily have an elongate, pipe-like shape, although this is preferred.

[0033] The advantage of using the planetary gear of a planetary gear rack as roller leads to the advantage that the hose only needs to be squeezed between the planetary gear and a support surface. The hose does not need to be threaded between further elements. Hence, there are no open fluid interfaces when the hose is built into the hose pump. Thus, the risk of contamination is reduced.

[0034] In a further preferred embodiment of the invention, the chambers are connected to the pump element in order to create a closed loop circuit if the support members are in a relative position in which the chambers are connected to each other. The closed fluidic loop on the one hand avoids any contamination of the substances inside the chambers and further allows in a simple manner for a reversion of the direction of flow of said substances.

[0035] In order to allow a visual, optical or any other form of an image-related evaluation of the test or analysis results, the device of the invention may be at least partially constituted of a transparent material, for example a transparent polymer, therewith allowing the observation of the reaction chamber or other parts of the device (including conduits).

[0036] The device according to the invention may advantageously be used with a base station, whereas that base station can comprise at least one drive for moving the support members with respect to each other. The base station may further comprise a pump drive. Such a system comprising at least a base station and a separate analysing device provides the advantage that complex and, thus, expensive technical devices can be incorporated into the base station, whereas the analysing device may be designed as a cheap disposable. This decreases the costs involved with the use of the analysing device or, respectively, the system according to the invention.

[0037] In a preferred embodiment of the invention, the pump element of the device comprises an elastic hose and the pump drive of the base station comprises a deformation element, preferably a roller element, which is moved along the length of the elastic hose, thereby locally deforming the elastic hose. This embodiment is advantageous in that the complex and expensive parts of the pump (which comprises the pump element of the device and the pump drive of the base station) are situated in the base station and only the elastic hose is part of the (preferably) disposable device. Therefore, the cost of production for the device can be kept low.

[0038] In case the base station further comprises a control and evaluation unit, the control of the drive(s) of the base station may be automated. This allows for a full automation of the analysing processes executed within the device.

[0039] The system according to the invention may further comprise at least one heating means. Said heating means may generate different temperature zones in the base station. Further, the base station may comprise a drive by which said temperature zones are movable with respect to the device. Hence, the temperatures inside the different chambers of the device may be adjusted to values which are best suited for the respective process steps carried out inside said chambers. This allows generating a temperature profile which is adapted to the successive process steps being conducted within the analysing device.

[0040] The hose pump according to the invention, the device according to the invention and the system according to the invention are preferably in the field of point-of-care applications, in particular in the field of nucleic acid analysis.

[0041] Below, the invention will be described with reference to figures that only show specific embodiments. The only figure shows a cartridge that contains a hose pump according to the invention in a schematic side view.

[0042] The hose pump (1) shown in the fig. has a hose (2) for taking up the fluid to be pumped. The hose pump (1) also has a planetary gear rack (3) with a ring gear (4), a sun gear (5), and five planetary gears (6) interposed between the ring gear (4) and the sun gear (5) and held by a cage.

[0043] In the moment of operation shown in the fig., six of the teeth (7) of one of the planetary gears (6) are in engagement with the hose (2) and squeeze a portion of the hose. This can be seen from the fig.; the engagement of the teeth (7) with the hose leads to the channel within the hose (2) being completely blocked. The hose's walls are in this particular moment at point (8).

[0044] As can be seen from the fig., the ring gear is a ring segment. Instead of a further ring segment that would complete the ring gear (4) to a ring, the ring gear (4) has an opening (9). A portion of the hose (2) is arranged inside this opening (9). The opening spans over an angle α that in the embodiment shown in the fig. is approximately 115 °. Consequently, the ring segment of the ring gear spans over an angle of 245 ° (360 °-α).

[0045] The hose pump (1) is provided with a support surface (10) that has a bent shape. This allows the portion of the hose (2) that is in contact with the support surface (10) to take up the shape of a ring segment. This ring segment spans over an angle β of approximately 90 °.

[0046] The opening of the ring gear and the ring segment of the hose span over an angle that is larger than an enclosure angle, which is defined to be = 360 ° / number of planetary gears of the planetary gear rack. The enclosure angle in the embodiment shown in the fig., which has five planetary gears of the planetary gear rack, is 72 °. The opening spans are α = 115 °. Since β equals 90 ° and is thus larger than 72 °, the design shown in the fig. ensures that in every instant of time at least one of the planetary gears is in engagement with a portion of the hose, and that for the number of degrees that β is larger than the enclosure angle, namely for approximately 18 °, two planetary gears are in engagement with the portion of the hose. This prevents the back flow of fluid from being pumped through the channel of the hose (2).

[0047] Given that the opening (9) of the ring gear (4) spans over an angle α = 115 °, and given that the hose (2) takes the shape of a ring segment over an angle of approximately 90 °, the embodiment shown in the fig. shows an embodiment where the angle that the ring segment shaped portion of the hose (2) takes up is approximately 80 % of the angle that the opening (9) takes up (β / α equals 90 °/115 ° = 80 %).

Claims

1. Hose pump (1) with a hose (2) for taking up the fluid to be pumped and with a planetary gear rack (3) having a ring gear (4), a sun gear (5) and at least two planetary gears (6) interposed between the ring gear (4) and the sun gear (5), **characterized in that**
at least one of the teeth (7) of the planetary gear (6) during one cycle of the planetary gear (6) around the sun gear (5) at least once engages with the hose (2) to squeeze a portion of the hose (2).

2. Hose pump according to claim 1, **characterized by** a support surface, the portion of the hose (2) being squeezed between the tooth (7) of the planetary gear (6) and the support surface (10).

3. Hose pump according to claim 1 or 2, **characterized in that** the ring gear (4) is a ring segment and that the ring gear (4) instead of a further ring segment that would complete the ring gear (4) to a ring has an opening (9), a portion of the hose (2) being arranged inside this opening (9).

4. Hose pump according to claim 3, **characterized in that** the ring segment of the ring gear (4) spans over more than 180°.

5. Hose pump according to claim 3 or 4, **characterized in that** the ring segment of the ring gear (4) spans over less than an angle is calculated by 360° minus an enclosure angle, the enclosure angle being calculated by the formula:

   enclosure angle = 360° / number of planetary gears (6) of the planetary gear rack (3).

6. Hose pump according to any one of claims 1 to 5, **characterized in that** the planetary gear in the direction of its rotational axis extends over the ring gear and that the portion of the planetary gear that extends over the ring gear engages into the hose to squeeze a portion of the hose.

7. Hose pump according to any one of claims 1 to 6, **characterized in that** a position sensor is arranged at the planetary gear or at the cage to determine the rotational position of the planetary gear in the planetary gear rack.

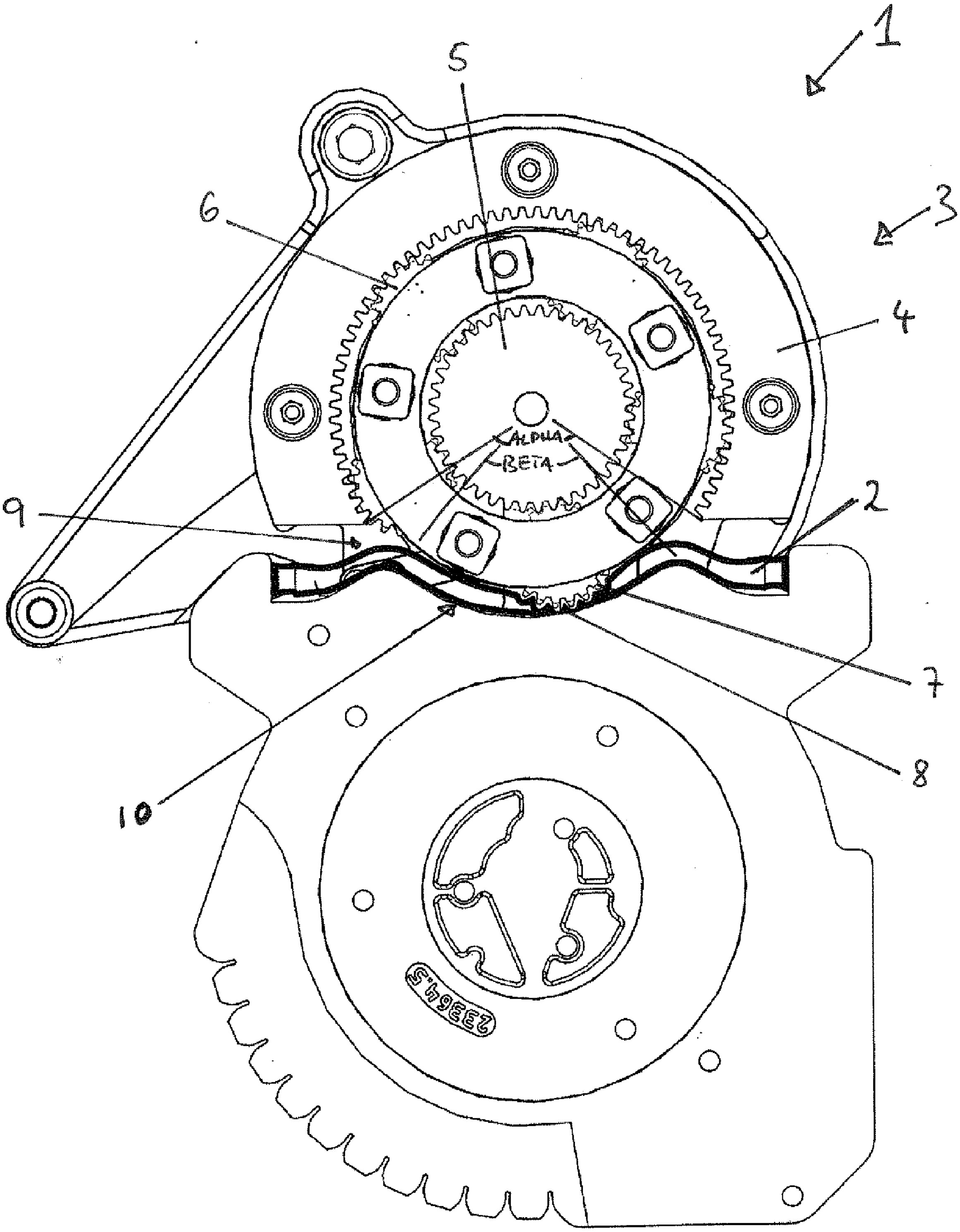
8. A device for analysing a sample, said device comprising at least one depot chamber and at least one process chamber, whereas the process chamber is integrated in at least one first support member and the depot chamber is integrated in at least a second support member, whereas the support members are arranged in that the process chamber is connectable with the depot chamber by a relative movement of the first and second support members with respect to each other, the device further comprising a pump element for transferring the substances inside the device from one chamber to another,
characterized in that the pump element is a hose pump (1) according to any one of claims 1 to 7.

9. System comprising:

   - a hose pump (1) according to any one of claims 1 to 7 or a device according to claim 8
   - a base station, said base station comprising at least a pump drive which acts on the hose pump (1) to drive the planetary gear around the sun gear.

10. System according to claim 9, **characterized in that** the hose pump according to any one of claims 1 to 7 or the device according to claim 8 is detachably connected to the base station.

11. Use of the hose pump (1) according to any one of claims 1 to 7 or of the device according to claim 8 or of the system according to one of the claims 9 to 10 and in the field of point-of-care applications, in particular in the field of nucleic acid analysis.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EUROPEAN SEARCH REPORT

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
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CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 14 18 8850

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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