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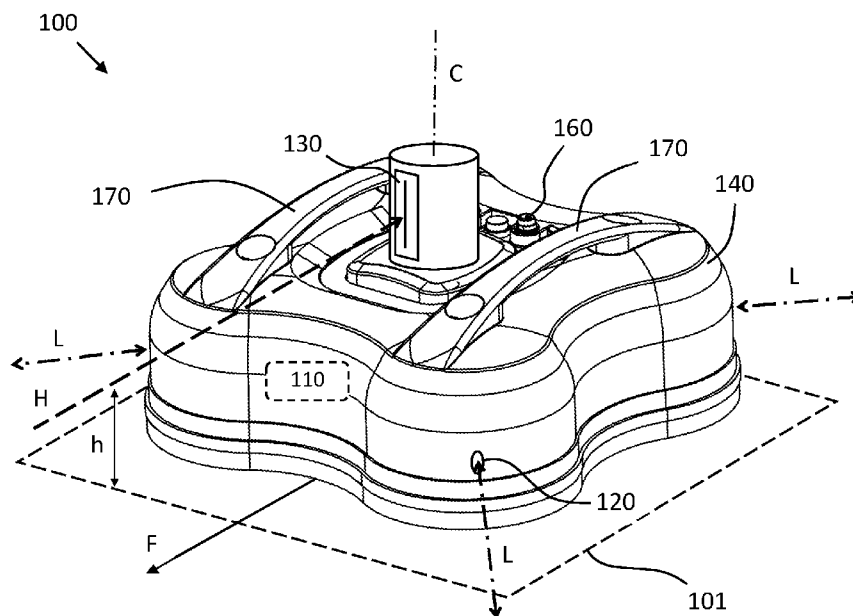


FIG. 1A

(57) Abstract: A concrete surface processing machine (100) for processing a concrete surface, wherein the concrete surface processing machine is arranged to be supported on the concrete surface by one or more support elements (150) extending in a base plane (101) of the machine parallel to the concrete surface, wherein the concrete surface processing machine comprises a control unit (110) connected to at least one linear photo sensor (130) extending transversally to the base plane (101), and wherein the control unit (110) is arranged to detect a height (h) of an incoming laser beam (H) relative to the base plane (101), based on a point of incidence of the incoming laser beam (H) on the linear photo sensor (130).



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TITLE

CONCRETE SURFACE MAPPING ROBOTS, SYSTEMS, AND METHODS
FOR PROCESSING CONCRETE SURFACES

5 TECHNICAL FIELD

The present disclosure relates to machines for processing concrete and stone surfaces, such as troweling machines, floor grinders and vacuum cleaners, and also to surface inspection robots. The disclosed machines comprise means for self-locomotion and are suitable for autonomous or remote
10 controlled operation. At least some of the machines disclosed herein are also arranged for autonomous mapping of a concrete surface.

BACKGROUND

Concrete surfaces are commonly used for flooring in both domestic and
15 industrial facilities. The sizes of concrete surface floors range from a few square meters for a domestic garage floor to thousands of square meters in larger industrial facilities. Concrete surfaces offer a cost efficient and durable flooring alternative and have therefore gained popularity over recent years.

Concrete surface preparation is performed in steps. After the concrete is
20 poured, the surface is first troweled and then grinded flat after the surface has reached a sufficient level of maturity. A matured concrete surface can then be polished to a glossy finish if desired. A floor grinder and/or a power trowel machine can be used to process the concrete surface efficiently.

Increased efficiency can be obtained if the different processing steps are
25 automated by the use of autonomous or semi-autonomous concrete surface processing machines. This type of processing normally requires some type of map of the surface. Reliable, efficient, and cost effective techniques for mapping a concrete surface are desired.

US20180004217A1 discloses a method for mapping an area for processing by autonomous robot vehicles but does not fully solve the challenges involved.

JP2016176203A discloses a concrete surface processing machine with height determination capabilities.

5

SUMMARY

It is an object of the present disclosure to provide improved concrete surface processing machines arranged for automated or remote controlled processing of a concrete surface.

- 10 This object is obtained by a concrete surface processing machine for processing a concrete surface. The concrete surface processing machine is arranged to be supported on the concrete surface by one or more support elements. The concrete surface processing machine comprises a control unit connected to at least one linear photo sensor extending transversally to the
- 15 base plane. The control unit is arranged to detect a height of an incoming laser beam relative to the base plane, based on a point of incidence of the incoming laser beam on the linear photo sensor. The control unit is also arranged to control a self-locomotion of the machine based on a difference between the detected height and a desired height, where the desired height is determined
- 20 in dependence of an estimated location of the concrete surface processing machine on the concrete surface.

- This means that the control unit is configured to selectively process the concrete surface in dependence of where on the concrete surface the machine is currently located. For instance, the machine may be configured to grind off
- 25 a given amount of material over the surface, which then means that the desired height will vary over the surface in dependence of an initially detected height at each location on the surface. This initially detected height may for instance be detected by an initial survey of the concrete surface to be processed, or as the processing of the concrete work surface progresses, i.e., the initially
- 30 detected height may also be the first detected height at a given location on the

concrete surface, before any substantial concrete processing operation has been performed at the location.

This way a reliable accurate and low-cost means for measuring concrete surface height is provided. This height data can be used to form an accurate topology map of the concrete surface if the machine travels around on the concrete surface.

According to aspects, the control unit is arranged to obtain a position of the machine on the surface, and to associate the detected height to the position on the surface. By associating height with location on the surface, a topology map can be formed. Also, locations on the surface having deviating height can be indicated to a user. The control unit may also be arranged to transmit topology information comprising the height to a remote device, where it can be used for further processing or made available for inspection by a user.

Thus, the above-mentioned object is also obtained by a concrete surface processing machine for processing a concrete surface. The concrete surface processing machine comprises a control unit connected to at least one linear photo sensor extending transversally to a base plane of the concrete surface processing machine. The control unit is arranged to detect a height of an incoming laser beam relative to the base plane, based on a point of incidence of the incoming laser beam on the linear photo sensor. The control unit is also arranged to record the height together with an associated estimated location of the machine on the concrete surface, as it moves around on the concrete surface.

The object is furthermore obtained by a concrete surface processing machine for processing a concrete surface, wherein the concrete surface processing machine comprises a control unit connected to at least one linear photo sensor extending transversally to a base plane of the concrete surface processing machine. The control unit is arranged to detect a height of an incoming laser beam relative to the base plane, based on a point of incidence of the incoming laser beam on the linear photo sensor. The control unit is also arranged to estimate a current location on the concrete surface associated with the

detected height h , and to record the detected height h as an initially detected height of the current location in case no initially detected height has previously been associated with the current location on the concrete surface.

According to aspects, the concrete surface processing machine comprises two
5 linear photo sensors arranged separated along a line parallel to the base plane. The control unit may then be arranged to determine a tilt of the machine with respect to the concrete surface based on a difference in the detected height of the incoming laser beam at the two linear photo sensors. This way a tilted portion of the concrete surface can be detected, which is an advantage.
10 This feature is particularly important in case a flat surface without tilt is desired. Of course, an initial tilt can be determined for one or more locations on the concrete surface. The initial tilt can then serve as a reference when processing the concrete surface.

According to aspects, the concrete surface processing machine comprises a
15 sensor arranged to detect a distance to the concrete surface along a normal vector to the concrete surface. This distance can be useful, e.g., in detection tool wear over time, since the distance from the sensor to the surface decreases with tool wear. Also, the control unit may optionally be arranged to adjust the detected height based on the detected distance to the concrete
20 surface, thus accounting for error sources related to, e.g., tool wear and the like.

According to aspects, the control unit is arranged to trigger generation of a signal indicating a tool wear in dependence of the detected distance to the concrete surface. This signal can, e.g., be sent to a control device of an
25 operator, or to some other maintenance function. An operator therefore automatically receives information about the tool wear and may, e.g., determine a suitable time for tool replacement.

According to aspects, the control unit is arranged to control a self-locomotion of the machine based on a difference between the detected height and a
30 desired height. By controlling self-locomotion in dependence of the difference between detected and desired height, it becomes possible to remain longer at

areas of the concrete surface which needs to be grinded more and move faster past areas which already are at or close to the desired height. This way a more selective processing of the concrete surface can be performed. The desired height may be an absolute pre-configured height, which can be appropriate if
5 a uniformly flat surface is desired, or a relative height determined in dependence of an initially detected height, such as would be desired in case a pre-determined amount of concrete is to be removed over the entire surface.

According to aspects, the machine is any of a floor grinder, power troweling machine, concrete surface surveying robot, vacuum cleaner, or a dedicated
10 mapping robot. Thus, the techniques disclosed herein are versatile in the sense that they can be applied together with many different types of machines.

According to aspects, the concrete surface processing machine comprises a suction device arranged to collect dust from the concrete surface, and a dust container for holding an amount of collected dust. Thus, the features disclosed
15 here are integrated with a dust extraction function. This is an advantage since both dust extraction and height detection can be performed by the same unit in an efficient manner.

There is also disclosed herein a concrete surface processing system comprising a plurality of concrete surface processing machines according to
20 the above discussion. The system also comprises a rotary laser device arranged to generate the incoming laser beam parallel to the concrete surface, which is used by the linear photo sensor to detect the height. This concrete surface processing system optionally comprises a remote device arranged communicatively coupled to at least one of the concrete surface processing
25 machines, allowing remote control of the concrete surface processing machine for a more efficient concrete surface processing operation.

According to aspects, the concrete surface processing machines are arranged to exchange the detected height with each other over wireless links. This way more reliable topology information can be determined since more than one
30 source contributes to the gathered height data. A topology map can also be

created faster in this way since the work can be divided between several machines.

Generally, all terms used in the claims are to be interpreted according to their ordinary meaning in the technical field, unless explicitly defined otherwise
5 herein. All references to "a/an/the element, apparatus, component, means, step, etc." are to be interpreted openly as referring to at least one instance of the element, apparatus, component, means, step, etc., unless explicitly stated otherwise. The steps of any method disclosed herein do not have to be performed in the exact order disclosed, unless explicitly stated. Further
10 features of, and advantages with, the present invention will become apparent when studying the appended claims and the following description. The skilled person realizes that different features of the present invention may be combined to create embodiments other than those described in the following, without departing from the scope of the present invention.

15

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will now be described in more detail with reference to the appended drawings, where

- Figures 1A-D show an example self-propelled floor grinding machine;
20 Figure 2 shows another example self-propelled floor grinding machine;
Figure 3 schematically illustrates a mapping system;
Figures 4-5 illustrate a principle of machine locomotion;
Figure 6 shows an example floor grinding machine;
Figure 7 schematically illustrates a machine for surface inspection;
25 Figure 8 shows a swarm of concrete surface processing machines;
Figure 9 illustrates a machine with dust collecting capability;
Figure 10 shows a swarm of concrete surface processing machines;
Figure 11 illustrates a dust collecting machine;

- Figure 12 schematically illustrates a surface inspection system;
Figures 13A-B show example concrete surface processing control devices;
Figures 14 illustrates a sequence of concrete processing operations;
Figures 15A-C are flow charts illustrating methods;
5 Figure 16 schematically illustrates a control unit; and
Figure 17 shows a computer program product;

DETAILED DESCRIPTION

The invention will now be described more fully hereinafter with reference to the
10 accompanying drawings, in which certain aspects of the invention are shown.
This invention may, however, be embodied in many different forms and should
not be construed as limited to the embodiments and aspects set forth herein;
rather, these embodiments are provided by way of example so that this
disclosure will be thorough and complete, and will fully convey the scope of
15 the invention to those skilled in the art. Like numbers refer to like elements
throughout the description.

It is to be understood that the present invention is not limited to the
embodiments described herein and illustrated in the drawings; rather, the
skilled person will recognize that many changes and modifications may be
20 made within the scope of the appended claims.

Figures 1A-D illustrate a machine 100 for processing concrete surfaces. The
machine is supported on the concrete surface by four rotatable tool heads.
Each tool head comprises a tool such as a grinding disc or the like, which is
held by a tool carrier 150. This particular machine comprises four tool carriers
25 150 arranged in a square configuration about a machine centroid C, as
illustrated in Figure 1C. An example machine 600 comprising three tool
carriers will be discussed in more detail below in connection to Figures 6, and
more than four tool carriers can also be used. The tool heads arranged to
process the concrete surface extend in a base plane 101 of the machine 100.

This base plane coincides with the concrete surface to be processed during operation of the machine 100. In other words, the base plane essentially constitutes the bottom surface of the machine 100.

The machines disclosed herein are advantageously used with rotatable tool carriers 150 arranged to rotate in a plane substantially parallel to the base plane 101, i.e., about respective axes of rotation normal to the base plane when the tool carrier is in an un-tilted position. These tools are inherently different from, e.g., a brush configured to rotate about an axis of rotation parallel to the base plane 101, as disclosed in JP2016176203A.

10 This particular machine 100 differs from known machines in that it is relatively small in both size and weight and does not comprise any manual control means such as a manual control handle or the like which an operator can use to steer the machine. Instead, this machine is self-propelled and comprises an on-board control unit 110, which control the various operations of the machine
15 without an operator having to go near the machine. The control unit 110 will be discussed in more detail below in connection to Figure 16. An example machine, like the machine 100 illustrated in Figures 1A-D, may be associated with a total weight less than 30kg, and preferably no more than 25kg. The machine footprint, i.e., the part of the surface 310 covered by the grinder, is
20 comprised in a square of dimensions 100cm by 100cm, and preferably no more than 70cm by 70 cm. The machine 100 is light enough to be carried by an operator, e.g., by the handles 170 arranged on the cover body 140 of the machine. This means that the machine is very easy to deploy and can be moved between work-sites in a convenient manner, e.g., in the back of a truck
25 of even a small car.

It is, however, appreciated that the herein disclosed techniques are in no way limited to use with small-sized concrete surface processing machines. Rather, the herein disclosed techniques for determining concrete surface heights and topologies may also be used with standard-sized floor grinders and power
30 trowels.

The machines discussed herein may be used for any of smoothing the concrete surface, troweling the concrete surface, grinding the concrete surface, and/or polishing the concrete surface. Thus, the machine 100 with the tool carriers 150 can be used for different types of concrete processing operations, such as troweling and grinding, by a convenient replacement of the tools on the rotatable tool carriers 150.

The machine 100 shown in Figures 1A-C may conveniently be equipped for floor grinding or floor polishing. The tool carriers 150 then hold tools arranged for abrasive operation, such as diamond tools for abrading the concrete surface. The abrasive tools can be of varying grit for different operations, i.e., course grit for leveling and fine grit for polishing. These tools may also be referred to as grinding heads.

Tool carriers holding tools for a troweling operation, i.e., troweling blades 160 are shown in Figure 1D. Similar tool carriers may be used to hold brushes on a dust collecting machine. Machines with dust collecting ability will be discussed below in connection to Figure 9.

In general, a tool carrier is a structure arranged to hold a concrete processing tool such as a grinding disc or a set of troweling blades. A tool carrier with an attached tool may be referred to as a tool head. A grinding head is a tool head arranged for grinding or polishing a concrete surface, while a troweling head is a tool head arranged for a troweling operation.

The tool carriers 150 can also be equipped with soft or resilient discs, such as rubber discs, which are designed to provide self-locomotion with a minimum degree of damage to the concrete surface. These transportation mode discs can be fitted to the machine in case the machine needs to traverse a sensitive concrete surface which has not fully matured yet. The radius of the discs may be configured to be larger than the radius of the grinding tools, to reduce impact to the concrete surface.

The transportation mode discs can also be used by the machine for surveying a concrete surface, i.e., by using one or more sensors configured to measure one or more properties of the concrete surface, such as any of a radar sensor,

a vision-based sensor, and/or a lidar sensor configured to detect scratch marks, uneven surface segments, discoloration, or damage in the concrete surface such as cracks. The one or more sensors may also comprise a surface temperature sensor and/or a moisture sensor, where the control unit is
5 arranged to determine a degree of concrete maturity associated with a segment of the concrete surface. The concrete maturity level can, e.g., be determined from a look-up table indexed by temperature and moisture level, or just temperature or moisture. Normally, the concrete maturity level can be determined with sufficient accuracy from temperature alone, although moisture
10 data may improve on the estimation accuracy in some case. These applications will be discussed in more detail below.

Data from a moisture sensor may also be useful in determining when to apply chemicals to the concrete surface, e.g., to prevent formation of coloring differences over the surface. Some forms of polishing operations require that
15 the concrete surface be associated with a moisture level below a threshold value. For instance, the residual moisture of the concrete surface may be required to be below about 4 CM%, otherwise coloring differences could appear later. CM stands for "Carbide Method". This is one of several scales of measurement used when measuring moisture in concrete.

20 The machine 100 optionally comprises a cover body 140 with one or more proximity sensors and/or impact sensors configured to detect when the cover body approaches and/or comes into contact with an obstacle. The machine control unit 110 may then be arranged to perform a situation avoidance maneuver in response to the one or more sensors detecting proximity and/or
25 contact with the obstacle. This sensory system can be configured to halt the machine when it comes into contact with an obstacle, or even before it actually hits the obstacle. Pressure sensors can be used to detect when the body hits an obstacle, while radar sensors and/or ultrasound sensors can be arranged to detect when an obstacle is about to be hit by the machine. The situation
30 avoidance maneuver may comprise bringing the grinder to a stop, or possibly executing an avoidance maneuver to avoid colliding with the obstacle.

The machine 100 is preferably although not necessarily battery powered or powered by one or more fuel cells. Electrical connectors 160 can be arranged on the top side of the machine for convenient access by a battery charger cable.

- 5 For larger jobs, i.e., to process larger surfaces, a plurality of machines 100 can be used in a floor grinding system. This type of system will be discussed in more detail below in connection to Figures 8 and 10.

The machines discussed herein comprise various features and abilities. Among these features is an ability to determine a height of the concrete surface
10 on which the machine is currently supported, by a relatively low cost linear photo sensor. This allows the machine, or an external control unit connected to the machine, to generate a topology map over the concrete surface. This topology map indicates, e.g., sections of the concrete surface which are higher or lower than the average surface height.

- 15 Another interesting ability is a simultaneous localization and mapping function. A key component of this feature is a laser range finder arranged pointing in a fixed direction from the machine. By rotating the entire machine about an axle normal to the concrete surface, an omnidirectional image of the surroundings is generated. The data obtained from this relatively low cost sensor is similar
20 to that obtained from a 360 degree lidar scanner, although this is a much more expensive sensor.

A third feature of the machines disclosed herein is a concrete surface inspection feature. This feature allows a machine to inspect the concrete surface and to determine one or more quality parameters of the surface, such
25 as if the surface comprises scratch marks or cracks.

A fourth feature of the concrete surface processing machines discussed herein is a dust collecting ability. By arranging suction devices and dust containers on the machine, an ability to collect dust from the concrete surface is obtained.

- A fifth feature of the concrete surface processing machines discussed herein
30 is the ability to dispense a mist of, e.g., water, in connection to the concrete surface processing. The purpose of this feature is to keep the abrasive tools

cool and to prevent over-heating which may result in tool glazing and inefficient concrete processing.

It is appreciated that all of these abilities may be freely combined in the concrete surface processing machine. Thus, although some features are
5 discussed in combination, this does not mean that they cannot be used separately, as will be readily understood by the skilled person.

The machines discussed herein may be powered by one or more rechargeable batteries configured to power one or more electric machines on the machine 100. These batteries may advantageously be charged using an inductive
10 charging circuit arranged to interface with an external power source and to recharge the one or more rechargeable batteries. For instance, a coil may be embedded directly into the concrete surface which is to be processed by the machine. An example of such a power source 840 will be discussed in more detail below in connection to Figure 8. The machine can then access the power
15 source as needed, much like a robotic lawn mower.

The concrete surface processing machines disclosed herein are arranged to be supported on the concrete surface by one or more support elements which may be tool carriers 150 or wheels 1110 as will be discussed below in connection to Figure 11. The support elements extend in a base plane 101 of
20 the machine parallel to the concrete surface 310.

The concrete surface processing machines may comprise a control unit 110 connected to at least one linear photo sensor 130 or linear image sensor extending transversally to the base plane 101. This linear photo sensor is arranged to register an incoming laser beam, such as an incoming laser beam
25 from a rotary laser. Rotary lasers are devices arranged to generate a laser beam parallel to some reference surface. Rotary lasers which generate horizontally aligned laser beams are often referred to as laser levels.

Basically, a linear photo sensor is a vertical array of photo sensors. A laser beam hitting a photo sensor in the array will trigger generation of a signal from
30 that photo sensor. A control unit 110 connected to the linear photo sensor can therefore detect the height at which a laser beam strikes the linear photo

sensor. A linear photo sensor may also comprise photo sensors arranged in matrix configuration, i.e., in two or more adjacent arrays of photo sensing elements. Such an array may not only detect the height at which an incoming laser beam strikes the array but may potentially also detect a tilt of the machine relative to, e.g., the horizontal plane.

With reference to Figure 1A, the control unit 110 is arranged to detect a height h of an incoming laser beam H relative to the base plane 101, or relative to some configured target height value, based on a point of incidence of the incoming laser beam H on the linear photo sensor 130. Rotary lasers are commonly used to establish a horizontal frame of reference at, e.g., construction sites and the like. The rotary laser is deployed at a surface and aligned to transmit a rotating laser beam parallel to the surface. The combination of the linear photo sensor 130 and the control unit 110 arranged to detect the height h enables the machine 100 to determine a surface topology of the concrete surface. By moving around on the concrete surface and measuring the height h , a topology map can be created. This topology map can then be used to plan or control concrete surface processing in order to arrive at a desired result, such as a flat concrete surface, or a concrete surface which has been grinded down by an equal amount over the surface.

In other words, there is disclosed herein a concrete surface processing machine for processing a concrete surface, wherein the concrete surface processing machine is arranged to be supported on the concrete surface by one or more support elements, wherein the concrete surface processing machine comprises a control unit 110 connected to at least one linear photo sensor 130 extending transversally to the base plane 101, and wherein the control unit 110 is arranged to detect a height h of an incoming laser beam H relative to the base plane 101, based on a point of incidence of the incoming laser beam H on the linear photo sensor 130, wherein the control unit 110 is arranged to record the height h together with an associated location on the concrete surface of the detected height h .

There is also disclosed herein a concrete surface processing machine for processing a concrete surface, wherein the concrete surface processing machine is arranged to be supported on the concrete surface by one or more support elements, wherein the concrete surface processing machine comprises a control unit 110 connected to at least one linear photo sensor 130 extending transversally to the base plane 101, and wherein the control unit 110 is arranged to detect a height h of an incoming laser beam H relative to the base plane 101, based on a point of incidence of the incoming laser beam H on the linear photo sensor 130, wherein the control unit 110 is arranged to control a self-locomotion of the machine based on a difference between the detected height h and a desired height, and where the control unit 110 is arranged to determine the desired height in dependence of an estimated location of the concrete surface processing machine on the concrete surface 310.

Thus, the concrete surface processing machine may be used to create a topology map of the concrete surface to be processed, and a user may then plan processing of the surface in dependence of the topology. For instance, some parts of the surface may be processed to be universally flat, while other surface portions may be processed so as to remove a fixed amount of material from the surface.

According to aspects, the control unit 110 is arranged to average the detected height h over time to determine an average detected height. The control unit 110 may also receive height data from other machines located on the same concrete surface. For instance, a swarm of concrete surface processing machines (see Figure 8 discussed below) may be used to process the concrete surface. These machines may then collaborate to generate a topology map of the concrete surface with higher accuracy due to the averaging. This averaging of course requires that the height data be timestamped and tagged with location. The time stamp can be used to weight the height data, where older data items are given less weight, since it becomes more likely that the section of surface has been processed by other machines since the height measurement was made.

One or more linear photo sensors 130 may be arranged on a part of the machine extending upwards from the concrete surface, as shown in Figure 1A. Alternatively, or as a complement, one or more of the linear photo sensors 130 may also be arranged integrated with the cover 140, as illustrated in Figure 2.

- 5 The concrete surface processing machine illustrated in Figure 2 comprises two linear photo sensors arranged separated along a line parallel to the base plane 101. The control unit 110 can then be arranged to determine a tilt of the machine with respect to the concrete surface based on a difference in the detected height h of the incoming laser beam H at the two linear photo sensors.
- 10 With reference to Figure 1B, the concrete surface processing machine 100 may also be arranged to rotate R about an axis C normal to the base plane 101 by the one or more support elements 150, 1110. The axis C may be a central axis of the machine 100, or some other axis. An eccentric rotation pattern is of course also possible. If the control unit 110 is connected to at least
- 15 one laser range finder 120 arranged pointing in a fixed direction from the concrete surface processing machine, a function similar to that of a 360 degree lidar device is obtained, albeit at a much lower cost. As the machine 100 rotates about the axis C , the laser range finder scans the surrounding environment and determines the range to the nearest object in all directions.
- 20 Thus, an “image” or representation of the surrounding environment is obtained. The control unit 110 can then be arranged to determine a boundary geometry 320 of the concrete surface 310 based on a sequence of ranges obtained by the laser range finder 120. It is appreciated that each complete revolution by the machine generates a sequence of ranges, which sequence of ranges will
- 25 repeat itself if the machine remains at a given location or will shift slightly between full rotations if the machine moves in some direction. The control unit 110 may perform simultaneous localization and mapping (SLAM) based on the sequence of ranges obtained from the laser range finder. Different SLAM methods will be discussed in more detail below in connection to Figure 3.
- 30 The concrete surface processing machine 100 may also comprise a downward looking sensor (not shown in Figures 1A-D), such as a downward looking radar

transceiver or laser rangefinder, arranged to detect a distance to the concrete surface 310 along a normal vector to the concrete surface. This downward looking rangefinder essentially measures the height of the support elements 150 mounted on the machine. If the machine is used for grinding, then the detected range by the downward looking rangefinder will decrease over time as the grinding tools get worn down. The control unit 110 may therefore adjust the detected height h of the concrete surface based on the detected distance to the concrete surface 310. Thus, tool type and tool wear will have little or no effect on the detected height h , which means that a topology map over the concrete surface 310 will be generated independently of tool wear and thus with higher accuracy compared to the case where tool wear is not accounted for. It is also appreciated that this sensor can be used to adjust the determined height for different types of tools. There is no longer a need to configure an exact tool height a-priori since the control unit 110 can use the data from the downward looking sensor to compensate for variation in tool height.

According to an example use-case, the machine 100 may first be calibrated without tools attached by placing it on the concrete surface 310. The downward looking sensor then determines the distance to the surface without tools attached. The height of the tool, after it has been attached, can then be determined based on a difference in height detected by the sensor.

The control unit 110 is optionally also arranged to trigger generation of a signal indicating a tool wear in dependence of the detected distance to the concrete surface 310. Thus, by constantly monitoring the distance from the sensor to the concrete surface, the control unit can detect when a given tool has been worn down enough to merit tool replacement. This feature is particularly useful when grinding concrete surfaces using abrasive tools. The control unit 110 may, e.g., trigger transmission of a tool replacement notification signal to a remote device, such as a remote control device of other type of wireless device. Examples of such devices 1310, 1320 are shown in Figures 13A and 13B. Alternatively, or in addition to the detected distance, the control unit 110 comprises a timer which measures to total accumulated grinding time for a given tool. The control unit can determine when a given tool has been worn

down enough to merit tool replacement by comparing the timer value to a preconfigured usage time associated with a given tool.

The machine 100 may comprise a plurality of laser range finders 120 arranged pointing in different respective directions from the concrete surface processing machine (four laser range finders 120 are shown in Figure 1B), or just a single
5 laser range finder (as illustrated in Figure 3, discussed below). The advantage of having more than one laser range finder is, of course, that more distance measurements can be made, which allows a greater degree of averaging and therefore also an increased accuracy in the range estimates. The range finders
10 are preferably arranged integrated in the cover body 140, as shown in Figure 1A. However, one or more laser range finders can also be arranged in, e.g., a central housing extending upwards from the machine as shown in Figure 2. It is appreciated that the laser range finders can be mounted in various locations on the machine 100.

15 The laser range finder is preferably a single-beam laser range finder which is arranged to determine a single range value per measurement scan. Thus, it is appreciated that the laser range finders discussed herein are inherently different from advanced lidar arrangements that acquire several ranges per measurement scan. Despite the beam of the laser range finder being narrow,
20 it will eventually spread over long distances due to the divergence of the laser beam, as well as due to scintillation and beam wander effects, caused by the presence of air bubbles in the air acting as lenses ranging in size from microscopic to roughly half the height of the laser beam's path above the earth. However, for the distances relevant here, the angular spread of the laser range
25 finder is well below five degrees, and often well below one degree in angular spread.

The laser range finder is a fixed direction laser range finder, meaning that it acquires a distance to the closest object along its fixed pointing direction. Thus, the laser range finders discussed herein are no able to scan an environment,
30 as a lidar system often does.

The lack of ability of the laser range finder to scan the surroundings of the concrete surface processing machine is compensated for by the fact that the entire concrete surface processing machine is arranged to rotate R about the axis C normal to the base plane 101, as indicated in Figure 1B. Thus, in a normal mode of operation, the machine 100 rotates about the axis C while moving around on the concrete surface. Any of the machines disclosed herein may comprise more than one range finder, and in particular two or more different types of laser range finders. For instance, a first laser range finder in the plurality of laser range finders may be configured for detecting range at a higher resolution compared to a second laser range finder in the plurality of laser range finders. The first laser range finder in the plurality of laser range finders may perhaps be configured for detecting range at a shorter distance compared to a second laser range finder in the plurality of laser range finders, but in return provide range data with higher resolution. This way high resolution close range distance data can be obtained from some of the laser range finders, while other range finders provide a lower resolution but increased range.

Optionally, one laser range finder in the plurality of laser range finders is configured in a different directional attitude compared to another laser range finder in the plurality of laser range finders 120. This way a better view of the surrounding environment can be obtained in the altitude dimension, i.e., in the dimension normal to the concrete surface. Some obstacles may, for instance, be protruding from a wall, where they cannot be seen by a laser range finder directed parallel to the concrete surface and close to the surface. However, a laser range finder directed with an attitude, i.e., pointing with an angle upwards from the concrete surface may be able to detect the obstacle. It is appreciated that obstacles located distanced from the concrete surface by a distance larger than a total height of the machine 100 will not present an obstacle to the machine. However, such obstacles may still be of interest if a map of the area is generated.

Optionally, at least one laser range finder 120 is arranged to scan in an elevation direction. This means that the laser range finder has an attitude

which changes over time, preferably rapidly, to generate distance data over a range of attitude angles.

Figure 3 shows an example application 300 of a concrete surface processing machine 100 which is processing a concrete surface 310. The surface is delimited by a boundary 320, this boundary can be a wall or some other type of structure, or it can be an imaginary boundary marked by boundary markers, such as laser reflectors (mirrors), radar reflectors, visual markers, or other types of markers. Thus, an operator can define the area to be mapped and processed, or a natural boundary like the walls of a room can be used to delimit the area.

A rotary laser 330 is deployed on the concrete surface. This rotary laser generates a laser beam H which impinges on the machine 100. Thus, the machine 100 may determine a height of the concrete surface section where the machine is located by means of the linear photo sensor 130 discussed above.

The height of the concrete surface 310 varies as illustrated by the equidistance lines 340, i.e., the surface is not perfectly flat. Some obstacles 350 are also present on the surface. The machines disclosed herein can be used to generate a topology map of the surface, including detecting the boundary geometry 320 and the differences in height 340 over the surface. This topology map can then be used by an operator to plan a concrete processing operation, and/or to evaluate the result of an already performed concrete processing operation. As will be discussed in more detail below, the concrete surface processing machine disclosed herein can also be used to evaluate a quality of the concrete surface, such as if the concrete surface comprises scratch marks, cracks, pores, or if the gloss is not according to specification. It is appreciated that obstacles, such as crates and other temporarily deployed tools, form part of the boundary geometry.

According to some aspects, the control unit 110 is arranged to obtain a position of the machine on the surface, and to associate the height h to the position on the surface. This data essentially constitutes a topology map of the surface.

The topology map data can either be used internally by the machine 100, and it can also be communicated to a remote device 360, such as one of the wireless devices 1310, 1320 illustrated in Figures 13A and 13B.

Some example concrete surface processing machines comprise a control unit
5 110 is arranged to detect a height h of an incoming laser beam H relative to the base plane 101, based on a point of incidence of the incoming laser beam H on the linear photo sensor 130 as discussed above, wherein the control unit 110 is arranged to record the height h together with an associated location on the concrete surface of the detected height h . This data then essentially forms
10 a topology map of a concrete surface, which can be used to plan a concrete surface processing operation.

An initially detected height associated with a location of the concrete surface may also be used with advantage in some concrete surface processing operations. This feature may be implemented as a concrete surface
15 processing machine 100, 600, 700, 900, 1100 for processing a concrete surface 310, wherein the concrete surface processing machine comprises a control unit 110 connected to at least one linear photo sensor 130 extending transversally to a base plane 101 of the concrete surface processing machine, and wherein the control unit 110 is arranged to detect a height h of an incoming
20 laser beam H relative to the base plane 101, based on a point of incidence of the incoming laser beam H on the linear photo sensor 130, wherein the control unit 110 is arranged to estimate a current location on the concrete surface associated with the detected height h , and wherein the control unit 110 is arranged to record the detected height h as an initially detected height of the
25 current location in case no initially detected height has previously been associated with the current location on the concrete surface.

Thus, as the concrete surface processing machine 100 moves around on the concrete surface 310 it checks whether it has previously visited the location and recorded an initial height for the location. If this is the case, then it
30 proceeds with the operation, i.e., the survey or the concrete processing operation. However, if the machine 100 has not been at the location previously,

then it records the detected height at that location as an initially detected height to be associated with the location. The initially detected heights together with the associated locations make up an initial topology map of the concrete surface prior to processing. This initial topology map can be used as reference
5 when processing the surface, e.g., if it is desired to remove a fixed amount of concrete across the surface. The initial topology map can also be used to determine a state of the concrete surface before and after one or more stages of concrete processing operations.

According to some aspects, the control unit 110 is arranged to transmit
10 topology information comprising the height h to a remote device 360, or to some other type of wireless device 1310, 1320 like those illustrated in Figures 13A and 13B. This topology information can comprise both the initially detected heights and the current heights (the last detected heights for each location on the surface). This allows an operator to monitor progress, and also
15 to determine how long the concrete processing operation is expected to take.

One interesting application where the machine 100 can be applied with advantage is an autonomous concrete processing operation. The control unit 110 is then arranged to control a self-locomotion of the machine based on a difference between the detected height h and a desired height over the
20 surface, such as a fixed reference height across the surface, a desired height determined relative to an initially detected height, or a desired topology obtained from some remote device 360. Thus, as the machine 100 moves over the surface which can be either autonomously mapped using the laser range finders or described by a pre-configured map accessible from the control unit
25 110, the current height h of the surface is detected and compared to the desired surface height. If there is a discrepancy between the current height and the desired height, the machine will process the surface until this discrepancy is reduced to a value below a tolerance setting. The concrete processing machine can then move across the surface and process it until a
30 desired result has been obtained.

- The desired height may be an absolute pre-configured height over some horizontal reference plane, in which case the machine 100 will process the surface until it is absolutely flat, or at least until it has a flatness below the tolerance level. Alternatively, the desired height is a relative height determined in dependence of an initially detected height. This means that a fixed amount of material is to be removed from the concrete surface. For instance, if the concrete processing operation targets a glossy finish, but total flatness is not so important, then the machine can be configured to remove, say 1-5mm of material from the surface, where about 2-3mm may be a preferred value.
- 10 If the machine reports the currently detected height, perhaps in relation to an initially detected height or some other type of desired height, then an operator can track the progress of the concrete surface processing operation in real time, which is an advantage. The remote device 360 may implement operator support software which tracks the progress of the concrete surface processing operation. This operator support software can also comprise a feature which predicts the time remaining until completion of the concrete processing operation. This can be achieved by monitoring a rate of progress (in terms of, e.g., mm per hour of a grinding process), and comparing the rate of progress to the difference between the currently detected heights over the surface in relation to the desired heights over the surface.
- 20 Such a feature can be supported by a concrete surface processing machine 100, 600, 700, 900, 1100 for processing a concrete surface 310, wherein the concrete surface processing machine comprises a control unit 110 connected to at least one linear photo sensor 130 extending transversally to a base plane 101 of the concrete surface processing machine, and wherein the control unit 110 is arranged to detect a height h of an incoming laser beam H relative to the base plane 101, based on a point of incidence of the incoming laser beam H on the linear photo sensor 130, wherein the control unit 110 is arranged to report the detected height h to a remote device 360 via wireless link.
- 25
- 30 The concrete surface processing machine may of course also report a desired height corresponding to the detected height, or a difference between the two.

The concrete surface processing machine may also report an initially detected height for the current location of the machine on the surface, of for a part of the surface. The heights can of course also be reported for locations in a grid or the like, in order to reduce the amount of data to be communicated to the remote device 360.

There are several ways in which the control unit 110 can establish a map of the concrete surface, comprising information about the boundary 320 and optionally also of any obstacles 350 present in the area.

According to some aspects, the control unit 110 comprises means for positioning the machine on the surface, such as a GPS or some form of indoor positioning system, e.g., based on radio beacons or lasers. In other words, the control unit 110 is optionally arranged to obtain a position of the machine on the surface 310, and to associate each determined range (or each determined sequence of ranges if the machine remains stationary while rotating) to a respective position of the machine on the surface. The machine may further comprise any of an electronic compass, a gyroscope and/or an inertial measurement unit, IMU, arranged to determine an angle of rotation of the concrete surface processing machine, wherein the control unit 110 is arranged to associate each determined range by the laser range finder to a respective angle of rotation of the concrete surface processing machine. Thus, the control unit is able to associate each range measurement by the laser range finder to an angle originating from a location on the surface, which means that the control unit 110 can easily establish a map over the surface.

The control unit 110 is optionally also arranged to determine a rotation velocity of the machine based on a frequency analysis of the determined ranges from the range finder. This is possible since the sequences of determined ranges will exhibit a repetitive pattern as the machine completes full rotations about the axle of rotation. By applying a frequency analysis to the determined range data, such as a Fast Fourier Transform or the like, the repetition frequency can be determined and consequently a rotational velocity of the machine 100 can be determined from the identified repetition frequency.

More advanced methods for simultaneous localization and mapping are known.

According to some optional aspects, the machine comprises one or more vision-based sensors. The control unit 110 can then be arranged to record
5 vision sensor data in dependence of machine pose and location, and potentially also communicate data from the vision-based sensors to a remote device 360, as shown in Figure 3. This data may, e.g., be used by an operator in a virtual reality (VR) application, where the operator may inspect the concrete surface without physically visiting the location. Techniques for VR are
10 known and will therefore not be discussed in more detail herein.

With reference to Figure 4, the machine 100 is self-propelled to move in a direction F in a controlled manner. This locomotion is generated by tilting one or more of the tool carrier axes A at an angle ϕ relative to the base plane 101. This tilting generates a difference in normal force N over the tool carrier such
15 that the rotating motion r by the tool carrier 110 generates a force F in a direction perpendicular to the tilting direction.

This tilting may be achieved by tilting the entire drive unit. Alternatively, a pulley or the like fixedly connected to the tool carrier 150 can be tilted to obtain the desired effect.

20 Figure 5 illustrates the tilting principle in more detail. Here, the tilt is illustrated by vector T in two dimensions. The generated force F is perpendicular to the direction of the tilt T, and the magnitude of the force depends on the level of tilt, such that a large tilt results in a relatively large force F while a smaller tilt, i.e., by a smaller angle, results in a smaller force F. The rotational velocity ω
25 also affects the generated force. For most grinding discs, the generated force increases more or less linearly with rotational speed up to a peak where the generated force starts to drop with rotational velocity. The tool head type in use and the maturity level of the concrete, i.e., the friction between tool head and concrete surface also has an effect on the magnitude of the generated
30 force F. The control unit 110 may thus control the generated forces by

controlling the direction of the tilt and the magnitude of the tilt by sending control signals to the tilt actuators.

This propulsion concept involving tool head tilting is associated with several advantages. For instance, since the forces are generated by tilting, the tool carriers can be arranged to rotate at the same absolute rotational velocity ω . This means that the electric machines can be optimized for a given fixed speed, where no speed control arrangements, or at least no complicated speed control arrangements, are required. Having at least three tool heads provides a level of stability to the machine which makes it suitable for operator-less control such as by remote control or autonomous operation. However, four or more tool heads are preferred since this also simplifies control of the propulsion and increases machine stability further.

At least one of the tool carriers 150 may furthermore be arranged to rotate with a variable rotational velocity ω , and the control unit can be arranged to control the variable rotational velocity ω of the tool head by the control signal to provide locomotion by the machine relative to the surface. It is appreciated that the speed of rotation has a similar effect on the machine force distribution as the normal load on the tool heads. Thus, the control unit 110 can generate a control signal to control rotational velocity and thereby obtain a desired motion by the machine relative to the concrete surface.

As illustrated in Figure 5, four tool carrier axes A may advantageously be arranged tiltable T with respect to the base plane 101. This means that four respective locomotion forces F_1 , F_2 , F_3 , F_4 are generated. A combined total force F_{total} is generated to provide locomotion and also a torque M_z about the machine mass center 510. A particular advantage with the arrangement 500 in Figure 5 is that the tool heads are arranged in pairs with opposite direction of rotation. The two tool heads in a pair provide a more straight forward motion control since they stabilize each other.

Each force F_i is a two-dimensional vector force in the plane 101. Its direction is, as discussed above, determined from the direction of rotation of the tool head and by the tilt angle T, as well as by the relative load on the tool head

compared to other tool heads. The magnitude of the force depends on many different factors. Some of the more important factors include the normal force which depends on the weight w_i on the tool head. This normal force can be adjusted in case a variable height suspension system is installed in connection
 5 to one or more of the tool heads. Thus, at least one of the tool carriers 150 may be configured with a variable height suspension configured to adjust a normal load associated with the tool carrier.

The magnitude of the force also depends on the rotational velocity of the grinding disc as discussed above. The relationship between these factors and
 10 the generated force is given by a function

$$\mathbf{F}_i = f(\mathbf{T}_i, \omega_i, w_i)$$

where $\mathbf{T}_i$ is the two-dimensional tilt vector representing direction and magnitude of the tilt of the i -th tool head, ω_i is the rotational velocity of the i -th tool head, and w_i is the weight on the i -th tool head which is indicative of the
 15 normal force of the tool head. This function is normally an approximation of the true relationship between parameters and the resulting force. This approximation can be arrived at by, e.g., a combination of analytical derivation and laboratory experimentation. A calibration routine can be conducted in order to adjust the function to match a given device and operating condition.

20 Generally, rotation about the mass center 510 is generated by the torque M_z

$$M_z = \sum_{i=1}^N \mathbf{r}_i \times \mathbf{F}_i$$

where $N=4$ in Figure 5. A turning motion by the machine can be achieved by varying the forces $\mathbf{F}_i$ such that a non-zero torque M_z is generated. Thus, turning of the machine, or motion along an arcuate path, can be achieved by
 25 varying the set of tilt angles $\{\arg(\mathbf{T}_i)\}_{i=1,\dots,4}$ or the set of tilt magnitudes $\{|\mathbf{T}_i|\}_{i=1,\dots,4}$ in a controlled manner, and/or by varying rotational velocity $\{\omega_i\}_{i=1,\dots,4}$ and/or by varying normal load $\{w_i\}_{i=1,\dots,4}$. It is appreciated that rotational velocity and weight are entirely optional control parameters. Only control of the tilt $\{\mathbf{T}_i\}_{i=1,\dots,4}$ is required to obtain basic functionality.

The total force F_{tot} (disregarding friction forces and the like) is given by

$$F_{tot} = \sum_{i=1}^N F_i$$

This quantity determines the direction of motion as well as the speed of the machine. The control unit 110 can be configured to generate a desired total force to move the machine in a desired direction, and/or a desired torque to rotate the floor grinder by generating one or more control signals to the different actuators on the machine 100. A combination of a non-zero total force and a non-zero torque about the mass center will generate a motion by the machine along an arcuate path. F_{tot} is preferably optimized for a given floor surfacing operation by the control unit 110.

The machines disclosed herein may be associated with different modes of operation. When in a transport mode of operation the machine may be configured by the control unit 110 to move relatively fast along a straight path towards a target destination without rotating about the machine centroid. This mode of operation is preferably used when moving the machine 100 from one place to another place. The transportation mode of operation may be optimized for transporting the machine 100 without leaving marks on the concrete surface, which may not be fully matured.

The machine 100 may also be associated with a work mode or active mode of operation. This mode is used, e.g., when grinding or troweling a concrete surface. The work mode of operation may comprise a rotation about the machine centroid in combination with a forward motion. The work mode of operation may be optimized for grinding performance or for troweling performance.

The force allocation by the control unit can be performed in a number of different ways. One way to perform the force allocation is to solve the system of force equations and torque equations analytically. Another, less computationally intensive way to perform the force allocation and tool head coordination is to maintain a set of look-up tables (LUT) with suitable tilt values

for different operations. Of course, these LUTs may need to be calibrated regularly.

Another method of force allocation and tool head coordination is to implement a feedback system where one or more sensors are used to detect a current motion behavior by the machine. Such sensors may comprise, e.g., any of inertial measurement units (IMU), electronic compasses, radar transceivers, global positioning system (GPS) and indoor location system transceivers. The control unit can then control the set of tilt angles $\{\arg(\mathbf{T}_i)\}_{i=1,\dots,4}$ and/or the set of tilt magnitudes $\{|\mathbf{T}_i|\}_{i=1,\dots,4}$ to obtain a desired motion by the machine. A set of rules can be formulated for how to obtain a desired effect. For instance, to increase speed in the forward direction, an increased tilt can be applied as shown in Figure 5. To reduce torque about the mass center, i.e., to drive more straight, tilt angles on one side can be changed, or tilt magnitudes on one side can be changed.

Depending on the surface processing task at hand, a limit on maximum allowable tilt angle may be imposed. This is because too large tilt angles may generate marks in the concrete surface, which of course is undesired.

Figure 6 illustrates another example machine 600 where the herein disclosed techniques may be used with advantage. This machine comprises three tool carriers 150, but versions with four or more tool carriers are also possible. The tool carriers 150 are arranged to be driven by a central electric machine 640 (a first motor) via a belt, chain, or gear drive arrangement. The first motor 640 is here shown as an electric machine, although a combustion engine can also be used. The entire bottom structure 610, often referred to as the “planet”, is rotated R about a center axis by a second motor 650. This type of dual drive machines is previously known and will therefore not be discussed in more detail herein. Note that the second motor 650 is optional, since the machine 600 can be brought into controlled rotation by means of the tool carriers 150, as discussed above in connection to Figure 4 and Figure 5.

The machine 600 comprises three tool carriers 150 arranged to rotate about respective tool carrier axes A, wherein at least one tool carrier axis is arranged

tiltable in two dimensions with respect to a base plane of the machine to generate locomotion by the machine relative to the surface. This tilting can be achieved, e.g., by using a set of servomechanisms and excentre members as discussed above to tilt the pulleys. However, the control of the tilting is a bit more advanced compared to the example discussed above in connection to Figure 5, since the rotation angle of the planet must also be accounted for.

In general, a control unit 110 can be configured to distribute forces over the tool heads to obtain a desired motion by the machine 600, e.g., a given speed in a given direction, perhaps complemented by a non-zero torque to obtain a planetary motion by the machine. The control unit then considers the following relationships

$$M_z = \sum_{i=1}^N \mathbf{r}_i \times \mathbf{F}_i$$

$$\mathbf{F}_{tot} = \sum_{i=1}^N \mathbf{F}_i$$

and determines a solution comprising a distribution of forces. Given a distribution of forces $\{\mathbf{F}_i\}$, the control unit then configures tool head parameters comprising tilt angle T_i , and optionally also β , ω_i , w_i

$$\mathbf{F}_i = f(T_i, \beta, \omega_i, w_i)$$

where β may be a function of time, ω_i is a rotational velocity of the i -th tool head, and w_i is a weight associated with the i -th tool head which can be adjusted by, e.g., controlling a variable height suspension system of a tool head. It is appreciated that rotational velocity and weight are entirely optional control parameters. Only control of the tilt $\{T_i\}_{i=1,\dots,3}$ is required to obtain basic functionality.

The planetary motion may be generated in either clock-wise or counter-clockwise direction depending on the force allocation $\{\mathbf{F}_i\}_{i=1,\dots,3}$ and tool head coordination. The planetary motion is preferably complemented by a forward motion by the machine 800 to move across the concrete surface as it grinds the concrete surface in a controlled manner.

The machine 600 comprises any of the laser range finder 120 and/or the linear photo sensor 130. Thus, the machine 600 may be arranged to perform all of the functions discussed above in connection to the machine 100, such as determining surface height in a topology map, and boundary geometry in a SLAM method.

It has been realized that the herein disclosed machines can also be used for investigating the quality of the concrete surface 310. By arranging various sensors to determine surface quality, a concrete surface can be surveyed before the concrete processing operation starts in order to provide input to operation planning, and the result of a concrete processing operation can be determined in order to make sure that the results is as expected, i.e., meets a specification.

Figure 7 illustrates a concrete surface processing machine 700, such as any of the machine 100, 600, for processing a concrete surface 310. The machine comprises means for self-locomotion and a control unit 110 arranged to control the means for self-locomotion. The means for self-locomotion may, e.g., comprise the tiltable tool holders discussed above in connection to, e.g., Figure 5, or driven wheels as illustrated in Figure 11. The machine 700 comprises one or more surface quality sensors 710, 720 connected to the control unit 110 and arranged to determine a local surface quality of the concrete surface 310. The local surface quality may, e.g., be indicative of the presence of scratch marks, cracks in the surface, and/or a level of surface gloss.

The one or more surface quality sensors may comprise a three-dimensional (3D) camera sensor. The control unit 110 can detect minute scratch marks and other undesired traits in the concrete surface by the output from the 3D camera. The one or more surface quality sensors may also comprise a radar sensor and an inertial measurement unit (IMU). The control unit 110 can detect irregularities such as scratches and cracks in the surface using the radar sensor. However, the vibration in the machine is likely to have a detrimental effect on the quality of the output data from the radar sensor. Thus, the control

unit 110 can be arranged to compensate the output signal from the radar sensor for vibration in the machine based on an output signal from the IMU.

The control unit 110 is furthermore arranged to control a self-locomotion of the machine to determine a plurality of local surface quality values associated with
5 respective different locations on the concrete surface 310.

The control unit 110 may advantageously be arranged to compare the plurality of local surface quality values to a pre-configured specification, and to output a validation result based on the comparison. Thus, the machine 700 can be used to perform an initial survey of a concrete surface and determine if the
10 surface is ready for a given type of processing. For instance, the machine 700 can be used to survey a concrete surface in order to determine if the surface is ready for processing by a finer grit, or if more processing by a courser grit abrasive tool is necessary due to the presence of scratches and the like. The machine 700 can also be used to validate the result of a concrete processing
15 operation, i.e., to verify that an intended result has been achieved, or if additional processing is required in order to fulfil a requirement specification.

The control unit 110 is arranged to generate a desired tool selection based on the determined local surface quality values. The tool selection may be displayed on a remote device like the devices 1310, 1320 illustrated in Figure
20 13A and 13B.

As shown in Figure 7, the machine 700 may optionally comprise any of the linear photo array for determining height h , and/or the laser range finder 120 for determining distances to surrounding objects like walls and other obstacles.

The machine 700 may be a stand-alone surface quality inspection robot which
25 only performs the function of surveying the concrete surface using the surface quality sensors 710, 720. Alternatively, the machine 700 may be arranged to perform additional functions, such as one or more concrete processing operations comprising troweling, grinding, polishing, and the like.

The machine 700 may also be arranged to perform SLAM operations, i.e., to
30 not only survey the quality of the concrete surface, but also perform

simultaneous localization of itself on the concrete surface and mapping of the concrete surface, as discussed above in connection to, e.g., Figure 3.

The one or more surface quality sensors may also comprise a laser scanner and/or a gloss sensor. Both laser scanners and gloss sensors are known and
5 will therefore not be discussed in more detail herein. A radar transceiver can also be used to evaluate surface quality, and also structural integrity of the concrete below the surface. The control unit 110 can then be arranged to detect cracks and pores in the concrete surface 310 based on an output signal from the radar transceiver.

10 The machine 700 may further comprise a particle sensor arranged to determine an amount of particles in the air surrounding the machine. The control unit 110 may then be arranged to trigger generation of a warning signal in case the amount of particles exceeds a preconfigured threshold value.

The machine 700 may optionally also comprise a gas sensor, such as a carbon
15 dioxide and/or carbon monoxide sensor arranged to determine an amount of carbon dioxide in the air surrounding the machine, wherein the control unit 110 is arranged to trigger generation of a warning signal in case the amount of carbon dioxide exceeds a preconfigured threshold value.

The warning signals may, e.g., be transmitted from the control unit 110 to a
20 remote device such as the remote device 360 discussed above in connection to Figure 3, or to a remote device such as the devices 1310, 1320 shown in Figures 13A and 13B. An operator may, for instance, configure an acceptable level of particles in the air, and/or level of carbon dioxide and/or level of carbon monoxide or other harmful or undesired gases, and receive a warning from the
25 machine 700 in case the relevant level in the area goes above this threshold. The threshold levels may also be configured in dependence of construction site requirements. Of course, other air quality sensors are also possible to mount on the machine 700, such as sensors for detecting various forms of gasses, Geiger counters, and the like.

30 The machines 700 discussed herein may also comprise a moisture sensor and/or a temperature sensor arranged to determine a moisture level and

temperature, respectively, of the concrete surface 310. The moisture and temperature data can be used to estimate a maturity level of the concrete surface, which can be used in determining when to start a given concrete processing operation. The moisture level can also be used to determine a
5 suitable time to apply chemicals and the like which require a certain moisture level to work efficiently.

The machine 700 may furthermore comprise a durometer arranged to determine a surface hardness level of the concrete surface 310. The durometer may comprise a hammer device arranged for determining concrete
10 hardness by determining a rebound energy.

Alternatively or in combination with the durometer, the machine 700 may comprise a device arranged to form a scratch in the concrete surface. The depth of this scratch can then be detected and used to determine a surface hardness level of the concrete surface 310. The depth may be determined
15 using a vision-based sensor such as a camera, or a laser sensor.

Figure 8 illustrates an example concrete surface processing system 800 comprising a plurality of machines 100 according to the above discussion. The plurality of machines may be of the same type, i.e., either small machines such as the machine 100, or larger machines such as the machine 600. However,
20 additional advantages may be obtained if a combination of different machines are used to process a larger concrete surface. The smaller machines may then process areas which require a lot of maneuvering, and which may be hard to access for the larger machines, while the larger machines may perform tasks where larger size is an advantage.

Figure 8 illustrates an example concrete surface processing system 800 comprising a plurality of concrete surface processing machines according to the discussions herein, and a rotary laser device 330 arranged to generate a laser beam H parallel to the concrete surface.

The system optionally comprises a remote device 360 arranged
30 communicatively coupled to at least one of the concrete surface processing machines.

One or more of the machines may be configured with transportation mode tool heads allowing the machine to traverse segments of the concrete surface which have not yet matured enough for processing. These machines may then function as scouts, surveying the concrete surface, and reporting back to the
5 other machines when a sufficient level of maturity has been reached on a given concrete segment for a given concrete processing operation.

The machines comprise a control unit 110 with a radio transceiver arranged to establish a communication link 820 to at least one other machine, or to a remote control device. This way the plurality of machines can form a mesh
10 network in order to exchange information and perform arbitration in case of any control conflicts which arise.

The plurality of machines may also be communicatively coupled, e.g., by wireless radio link, to a central control unit 360 arranged to control a floor grinding operation over a concrete surface 310. This central control unit 360
15 may control the “swarm” of machines to complete a larger floor grinding task.

The machines may furthermore comprise a positioning system arranged to position the respective machines in a coordinate system relative to the concrete surface 310. This positioning data can be used by the external control unit 360 in order to control the floor processing operation. The machines may
20 also be arranged for autonomous operation, i.e., for processing the concrete surface in a collaborative manner without guidance from a central control unit 360.

An inductive charging station 840 may be embedded into the concrete surface. The machines 100 may then regularly return to the charging station to
25 replenish the energy storage, i.e., charge the on-board batteries.

One or more concrete maturity sensors 830 may also be embedded into the concrete surface. This sensor measures, e.g., temperature and moisture in the concrete slab and is thus able to determine a current concrete maturity level of the concrete surface 310. Based on a time sequence of data samples, the
30 maturity sensor, or the control unit 110, may extrapolate to estimate a future concrete maturity level over the concrete surface. This allows the swarm of

machines to work where it is as most efficient given the maturity levels over the concrete surface.

Figure 9 illustrates some other aspects of the disclosed machines for concrete surface processing. This machine 900 comprises a dust container 910
5 arranged to hold a quantity of dust. The machine also comprises a suction device 920 which is only schematically illustrated in Figure 9. The suction device 920 and the dust container 910 allow the machine 900 to collect dust from the concrete surface 310, such as dust generated during grinding.

The machine 900 may comprise tools for grinding, i.e., rotatable discs for
10 abrasive operation. The machine 900 then performs both grinding as well as collecting the dust generated by the grinding.

The machine 900 may also be configured as a dedicated dust collector machine. In this case there are no grinding tools attached. Instead, the machine may comprise brushes configured on the tool holders 150. One
15 possible realization of this type of dust collecting machine is obtained if the troweling blades in Figure 1D is replaced by brushes. The dust container 910 may be used as supporting structure for one or more of the sensors on the machine, as schematically illustrated in Figure 9.

Figure 10 illustrates a concrete surface processing system 1000. The system
20 comprises a plurality of machines 100, 900 which are processing the concrete surface in a collaborative manner. The system is similar to the concrete surface processing system discussed in connection to Figure 8, but this system also comprises one or more machines 900 with the suction device 920 arranged to collect dust from the concrete surface 310, and the dust container 910 for
25 holding an amount of collected dust. The system also comprises a central dust collection station 1010 which is arranged to empty the dust containers of the machines with dust collecting ability. The machines then navigate to the central dust collection station 1010 whereupon the dust container is emptied via a hose or other form of connector. The dust containers 910 may of course also
30 be manually emptied by an operator. In this case, the control unit 110 may

transmit a signal to, e.g., a remote wireless device 1310, 1320 indicating a need for emptying the dust container 910.

The teachings herein may also be applied to more conventional types of dust containers, such as the dust collector 1100 illustrated in Figure 11. This machine 1100 has been equipped with the same type of control unit 110 as discussed above and may comprise any of the linear photo array sensor 130 and/or the range finder 120, enabling it to determine a topology map, and also to perform SLAM based on the range data from the range finder sensor 120. The control unit 110 may control motion of the dust collector 1100 by driven wheels 1110, powered by electrical machines. Thus, a conventional dust collector such as the dust collector 1100 may be equipped with sensor systems 120, 130 and a control unit 110, to perform topology map generation, as well as surface mapping and potentially also surface quality analysis. Figure 12 shows a version of the machine discussed above in connection to Figure 7, but now based on a machine supported on wheels, such as the dust collector 1100 in Figure 11. The machine 1200 has the same capabilities as the machine in Figure 7 when it comes to surveying the concrete surface 310.

The machine 1200 is supported on the concrete surface by a plurality of support elements 1110 extending in a base plane 101 of the machine parallel to the concrete surface 310, i.e., the wheels on the machine 1200 are arranged to span the base plane 101 of the machine.

It is noted that the machine 1200 may be configured to carry one or more of the sensor devices 120, 130, 710, 720, and that the devices can be used independently of each other. Thus, it is possible that the machine 1200 only comprises the support elements 1100 and the linear photo sensor 130.

The machine 1200 may of course also comprise means for communicating over wireless link with a remote device 360.

The machine 1200 may also comprise means for weighting the amount of collected dust and slurry from the concrete surface. This amount of dust and slurry can be used to estimate a cutting rate/performance of used abrasive tools. This measure of cutting rate/performance can be used by the remote

device 360 in predicting a time of completion of a concrete surface processing operation, as discussed above. The measurement of amount of collected dust and slurry may be used as a complement to the measurement of detected height at a location on the concrete surface, and a difference between detected
5 height and desired height, as discussed above.

Figures 13A and 13B illustrate example remote controls 1310, 1320 which can be used to control the different machines 100, 600, 700, 900, 1100 discussed herein. The remote control device 1310 is a conventional remote control device which connects to the control unit 110 of the machine via wireless radio link.
10 The remote control device 1320 in Figure 13B is a tablet or smartphone which connects to the control unit 110 to issue control commands and/or to receive status reports and other information back from the control unit 110.

Figure 14 illustrates a process 1400 for processing a concrete surface 310. This process may be performed by different types of machines or by the same
15 machine. The process comprises surveying 1410 the concrete surface in preparation for processing the concrete surface. This step may comprise, e.g., evaluating a quality of the concrete surface, determining, and suggesting suitable tools for performing concrete processing, and perhaps indicating suitable time windows for each processing step. The process then comprises
20 a step 1420 where the surface processing system is configured. This step may comprise, e.g., inputting directives to a swarm of concrete surface processing machines or programming a single concrete surface processing machine. The process then continues with a step 1430 where the concrete surface is processed. This step may comprise troweling the surface, grinding the surface,
25 and/or polishing the surface. A final step 1440 comprises verifying that an intended result has been achieved. This step may comprise evaluating surface quality by, e.g., the machine 700 discussed in connection to Figure 7.

Figure 15A is a flow chart illustrating a method for processing a concrete surface 310. The method comprises deploying Sa1 a rotary laser device 330
30 on or in connection to the concrete surface 310. The rotary laser device 330 may either be placed directly onto the floor or mounted onto a wall or the like

in connection to the concrete surface of interest. The rotary laser device is arranged to generate a laser beam H. The method also comprises configuring Sa2 a concrete surface processing machine 100, 600, 900, 1100 supported on the concrete surface by one or more support elements 150, 1110 extending
5 in a base plane 101 of the machine parallel to the concrete surface 310, connecting Sa3 a control unit 110 of the machine to at least one linear photo sensor 130 on the machine extending transversally to the base plane 101, and detecting Sa4 a height h of the laser beam H relative to the base plane 101, by the linear photo sensor 130, based on a point of incidence of the incoming
10 laser beam H on the linear photo sensor 130.

Figure 15B is a flow chart illustrating a method for processing a concrete surface 310. The method comprises configuring Sb1 a concrete surface processing machine 100, 600, 900, 1100 supported on the concrete surface by one or more support elements 150, 1110 extending in a base plane 101 of
15 the machine parallel to the concrete surface 310, controlling Sb2 the concrete surface processing machine to rotate R about an axis C normal to the base plane 101 by the one or more support elements 150, 1110, connecting Sb3 a control unit 110 on the machine to at least one laser range finder 120 arranged pointing in a fixed direction from the concrete surface processing machine, and
20 determining Sb4 a boundary geometry 320 of the concrete surface 310 based on a sequence of ranges obtained by the laser range finder 120.

Figure 15C is a flow chart illustrating a method for processing a concrete surface 310. The method comprises configuring Sc1 a concrete surface processing machine 100, 600, 900, 1100 for processing the concrete surface
25 310, wherein the machine comprises means for self-locomotion and a control unit 110 arranged to control the means for self-locomotion, connecting Sc2 one or more surface quality sensors 710, 720 to the control unit 110, wherein the surface quality sensors are arranged to determine a local surface quality of the concrete surface 310, and controlling Sc3 self-locomotion of the
30 machine by the control unit 110 to determine a plurality of local surface quality values associated with respective different locations on the concrete surface 310.

Figure 16 schematically illustrates, in terms of a number of functional units, the general components of a control unit 110, 1600. Processing circuitry 1610 is provided using any combination of one or more of a suitable central processing unit CPU, multiprocessor, microcontroller, digital signal processor DSP, etc.,
5 capable of executing software instructions stored in a computer program product, e.g. in the form of a storage medium 1630. The processing circuitry 1610 may further be provided as at least one application specific integrated circuit ASIC, or field programmable gate array FPGA.

Particularly, the processing circuitry 1610 is configured to cause the device
10 180 to perform a set of operations, or steps, such as the methods discussed in connection to Figures 15A-C and the discussions above. For example, the storage medium 1630 may store the set of operations, and the processing circuitry 1610 may be configured to retrieve the set of operations from the storage medium 1630 to cause the device to perform the set of operations.
15 The set of operations may be provided as a set of executable instructions. Thus, the processing circuitry 1610 is thereby arranged to execute methods as herein disclosed.

The storage medium 1630 may also comprise persistent storage, which, for example, can be any single one or combination of magnetic memory, optical
20 memory, solid state memory or even remotely mounted memory.

The device 1600 may further comprise an interface 1620 for communications with at least one external device. As such the interface 1620 may comprise one or more transmitters and receivers, comprising analogue and digital components and a suitable number of ports for wireline or wireless
25 communication.

The processing circuitry 1610 controls the general operation of the control unit 1600, e.g., by sending data and control signals to the interface 1620 and the storage medium 1630, by receiving data and reports from the interface 1620, and by retrieving data and instructions from the storage medium 1630.

The control unit 110, 1600 may be configured to perform all of the functions discussed above, e.g., in relation to controlling tilt angles and the like to move the machines in relation to a concrete surface.

Figure 17 illustrates a computer readable medium 1710 carrying a computer
5 program comprising program code means 1720 for performing the methods illustrated in Figures 15A-C, when said program product is run on a computer. The computer readable medium and the code means may together form a computer program product 1700.

CLAIMS

1. A concrete surface processing machine (100, 600, 700, 900, 1100) for processing a concrete surface (310), wherein the concrete surface processing machine is arranged to be supported on the concrete surface by one or more support elements (150, 1110) extending in a base plane (101) of the machine parallel to the concrete surface (310),
5 wherein the concrete surface processing machine comprises a control unit (110) connected to at least one linear photo sensor (130) extending transversally to the base plane (101), and
10 wherein the control unit (110) is arranged to detect a height (h) of an incoming laser beam (H) relative to the base plane (101), based on a point of incidence of the incoming laser beam (H) on the linear photo sensor (130),
wherein the control unit (110) is arranged to control a self-locomotion of the machine based on a difference between the detected height (h) and a desired height,
15 height,
where the control unit (110) is arranged to determine the desired height in dependence of an estimated location of the concrete surface processing machine on the concrete surface (310).
2. The concrete surface processing machine (100, 600, 700, 900, 1100) according to claim 1, wherein the control unit (110) is arranged to obtain a position of the machine on the surface, and to associate the height (h) to the position on the surface.
3. The concrete surface processing machine (100, 600, 700, 900, 1100) according to any previous claim, wherein the control unit (110) is arranged to transmit topology information comprising the height (h) to a remote device (360).
25 (360).
4. The concrete surface processing machine (100, 600, 700, 900, 1100) according to any previous claim, comprising two linear photo sensors arranged separated along a line parallel to the base plane (101), wherein the control unit
30 (110) is arranged to determine a tilt of the machine with respect to the concrete

surface based on a difference in the detected height (h) of the incoming laser beam (H) at the two linear photo sensors.

5. The concrete surface processing machine (100, 600, 700, 900, 1100) according to any previous claim, comprising a sensor arranged to detect a distance to the concrete surface (310) along a normal vector to the concrete surface.
6. The concrete surface processing machine (100, 600, 700, 900, 1100) according to claim 5, wherein the control unit (110) is arranged to adjust the detected height (h) based on the detected distance to the concrete surface (310).
7. The concrete surface processing machine (100, 600, 700, 900, 1100) according to claim 5 or 6, wherein the control unit (110) is arranged to trigger generation of a signal indicating a tool wear in dependence of the detected distance to the concrete surface (310).
8. The concrete surface processing machine (100, 600, 900) according to any previous claim, wherein the desired height is an absolute pre-configured height as function of concrete surface location.
9. The concrete surface processing machine (100, 600, 900) according to any previous claim, wherein the desired height is a relative height determined in dependence of an initially detected height.
10. The concrete surface processing machine (100, 600, 900) according to any previous claim, wherein the desired height is determined in dependence of a desired concrete surface quality.
11. The concrete surface processing machine (100, 600, 700, 900, 1100) according to any previous claim, wherein the control unit (110) is arranged to average the detected height (h) over time to determine an average detected height.
12. The concrete surface processing machine (100, 600, 700, 1100) according to any previous claim, wherein the machine is any of a floor grinder,

power troweling machine, concrete surface surveying robot, vacuum cleaner, or a dedicated mapping robot (100, 600).

13. The concrete surface processing machine (100, 600, 700, 900, 1100) according to any previous claim, comprising a suction device (920) arranged
5 to collect dust from the concrete surface (310), and a dust container (910) for holding an amount of collected dust.

14. A concrete surface processing system (800, 1000) comprising a plurality of concrete surface processing machines according to any previous claim, and a rotary laser device (330) arranged to generate an incoming laser beam (H)
10 parallel to the concrete surface.

15. The concrete surface processing system (800, 1000) according to claim 14, further comprising a remote device (360) arranged communicatively coupled to at least one of the concrete surface processing machines.

16. The concrete surface processing system (800, 1000) according to claim
15 14 or 15, wherein the concrete surface processing machines are arranged to exchange the detected height (h) with each other over wireless links (820).

17. A method for processing a concrete surface (310), comprising
deploying (Sa1) a rotary laser device (330) on or in connection to the concrete surface (310) to generate a laser beam (H),
20 configuring (Sa2) a concrete surface processing machine (100, 600, 700, 900, 1100) supported on the concrete surface by one or more support elements (150, 1110) extending in a base plane (101) of the machine parallel to the concrete surface (310),

connecting (Sa3) a control unit (110) of the machine to at least one linear photo
25 sensor (130) on the machine extending transversally to the base plane (101), and

detecting (Sa4) a height (h) of the laser beam (H) relative to the base plane (101), by the linear photo sensor (130), based on a point of incidence of the incoming laser beam (H) on the linear photo sensor (130),

18. A concrete surface processing machine (100, 600, 700, 900, 1100) for processing a concrete surface (310),
wherein the concrete surface processing machine comprises a control unit (110) connected to at least one linear photo sensor (130) extending
5 transversally to a base plane (101) of the concrete surface processing machine, and
wherein the control unit (110) is arranged to detect a height (h) of an incoming laser beam (H) relative to the base plane (101), based on a point of incidence of the incoming laser beam (H) on the linear photo sensor (130),
10 wherein the control unit (110) is arranged to record the height (h) together with an associated location on the concrete surface of the detected height (h).
19. A concrete surface processing machine (100, 600, 700, 900, 1100) for processing a concrete surface (310),
wherein the concrete surface processing machine comprises a control unit
15 (110) connected to at least one linear photo sensor (130) extending transversally to a base plane (101) of the concrete surface processing machine, and
wherein the control unit (110) is arranged to detect a height (h) of an incoming laser beam (H) relative to the base plane (101), based on a point of incidence
20 of the incoming laser beam (H) on the linear photo sensor (130),
wherein the control unit (110) is arranged to estimate a current location on the concrete surface associated with the detected height (h), and
wherein the control unit (110) is arranged to record the detected height (h) as an initially detected height of the current location in case no initially detected
25 height has previously been associated with the current location on the concrete surface.
20. A concrete surface processing machine (100, 600, 700, 900, 1100) for processing a concrete surface (310),

wherein the concrete surface processing machine comprises a control unit (110) connected to at least one linear photo sensor (130) extending transversally to a base plane (101) of the concrete surface processing machine, and

- 5 wherein the control unit (110) is arranged to detect a height (h) of an incoming laser beam (H) relative to the base plane (101), based on a point of incidence of the incoming laser beam (H) on the linear photo sensor (130),

wherein the control unit (110) is arranged to report the detected height (h) to a remote device (360) via wireless link.

1/10

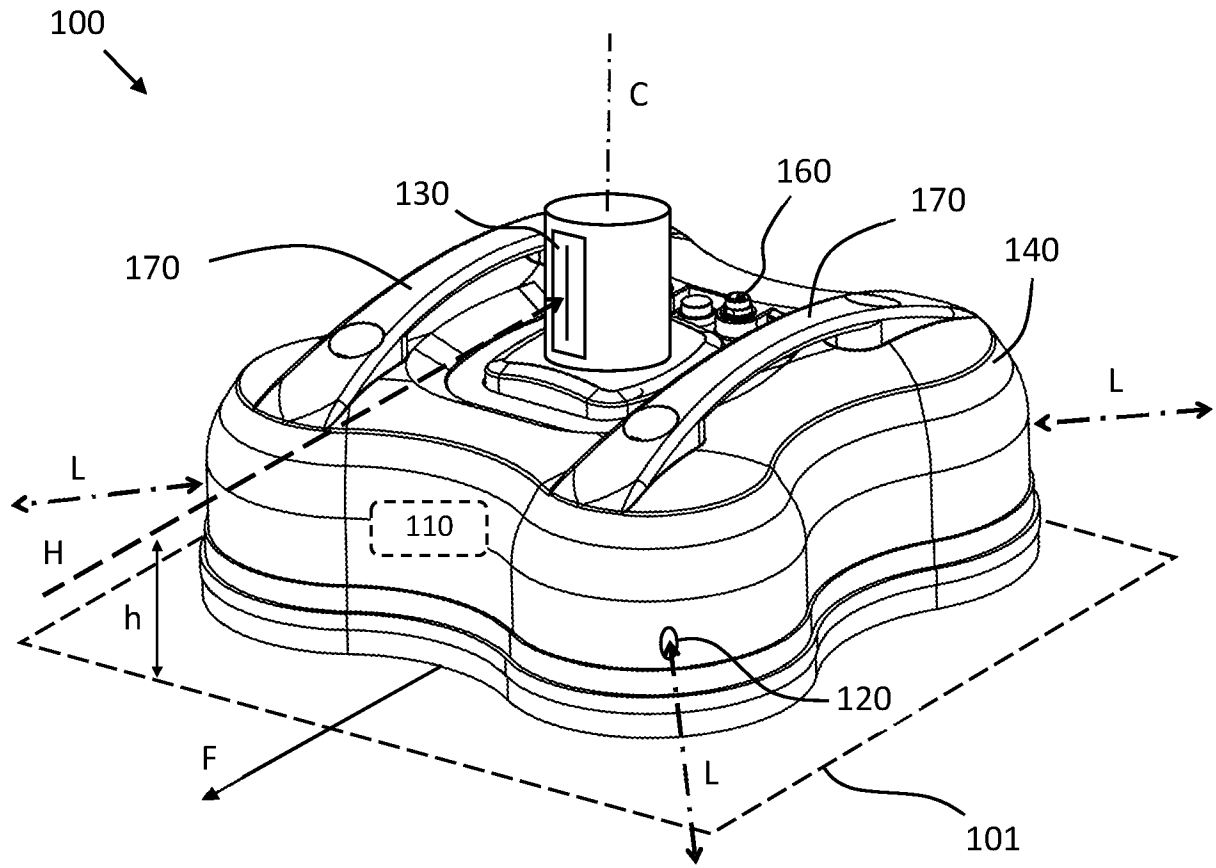


FIG. 1A

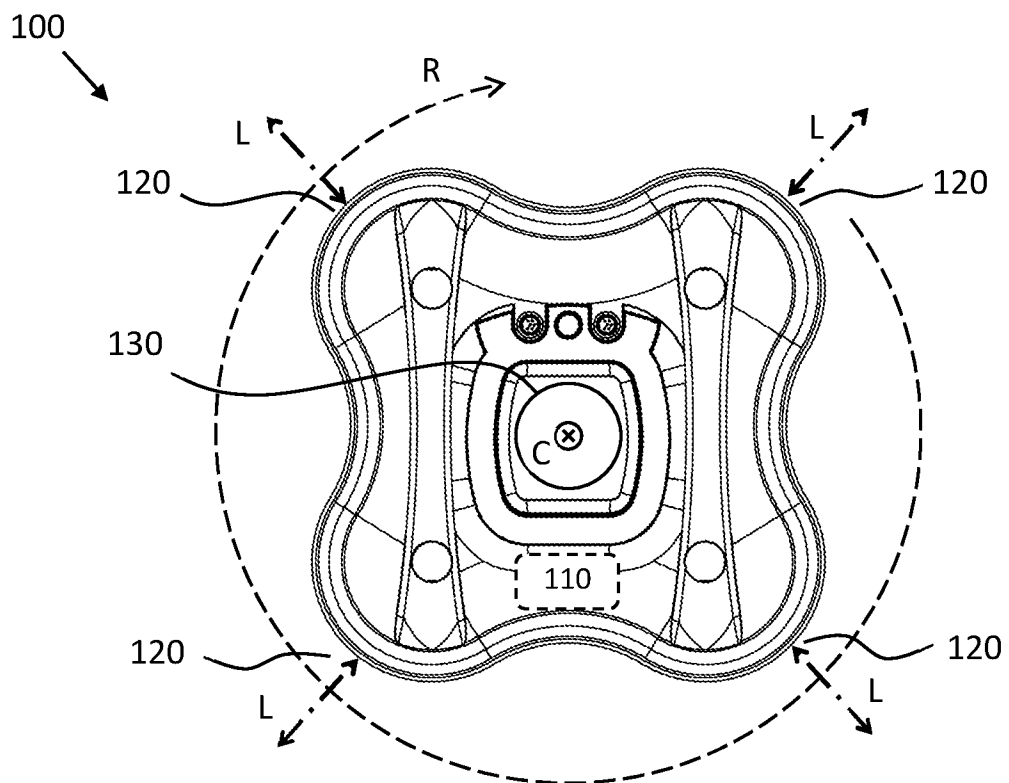


FIG. 1B

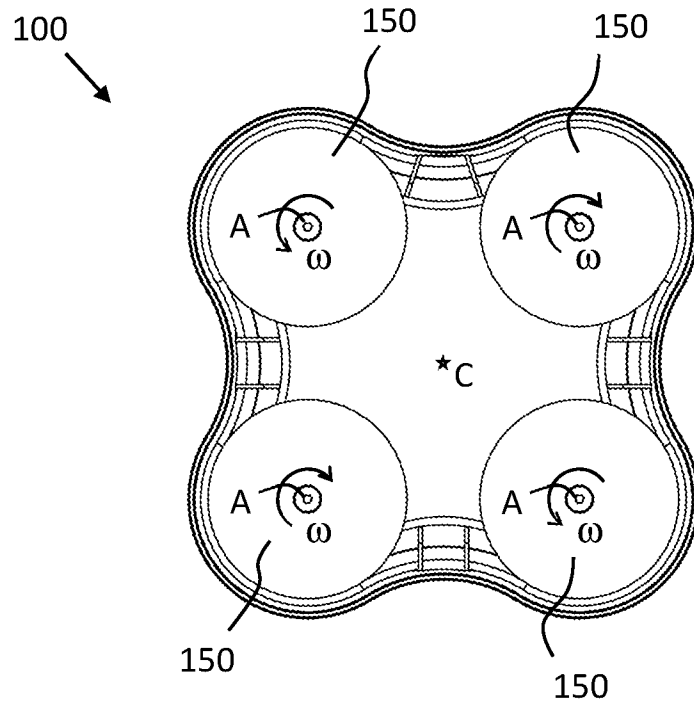


FIG. 1C

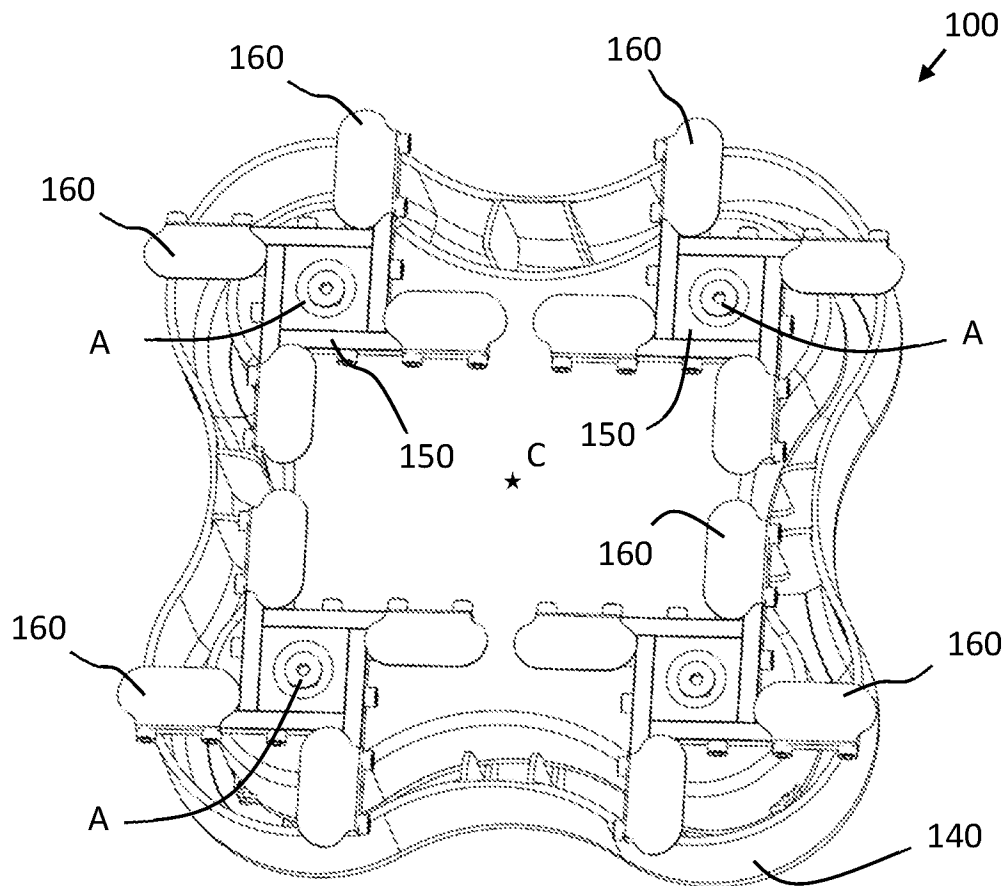


FIG. 1D

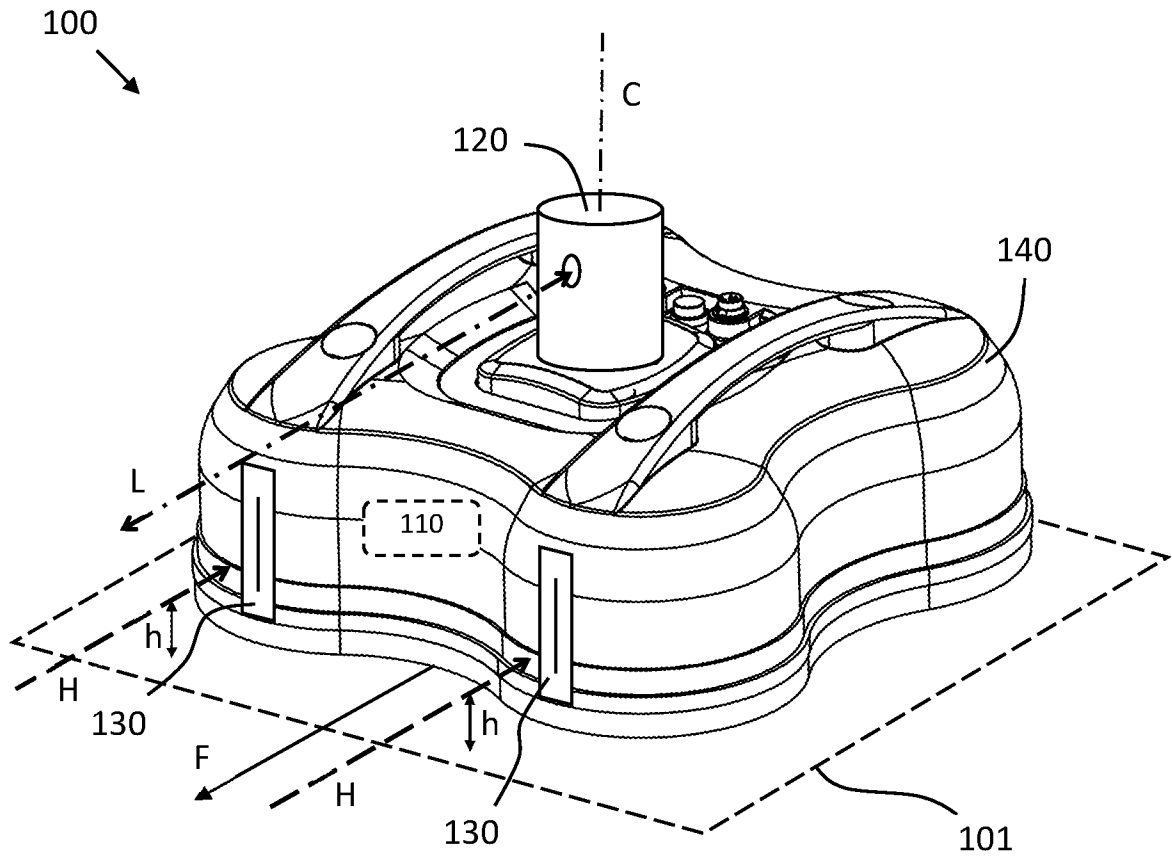


FIG. 2

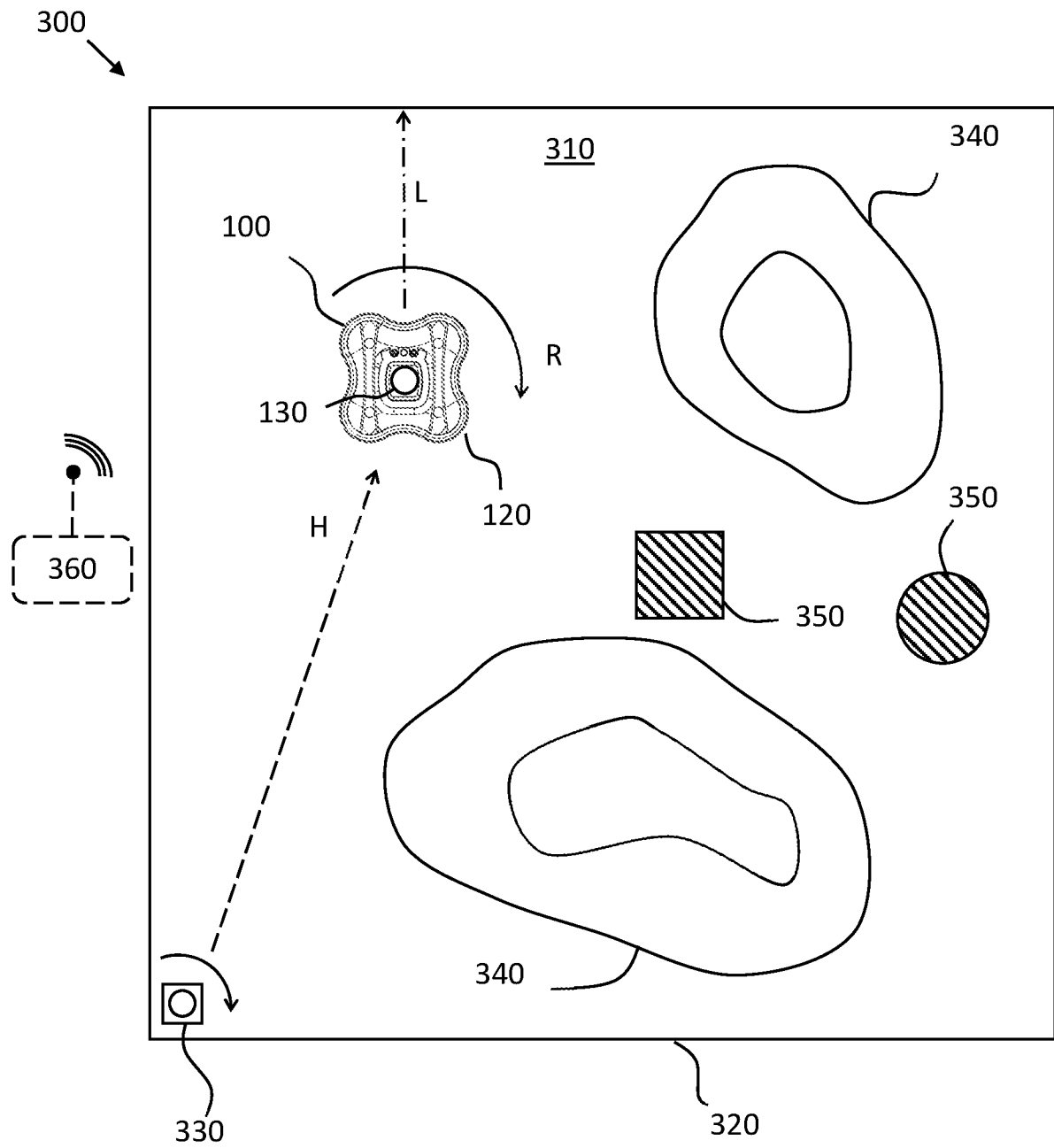
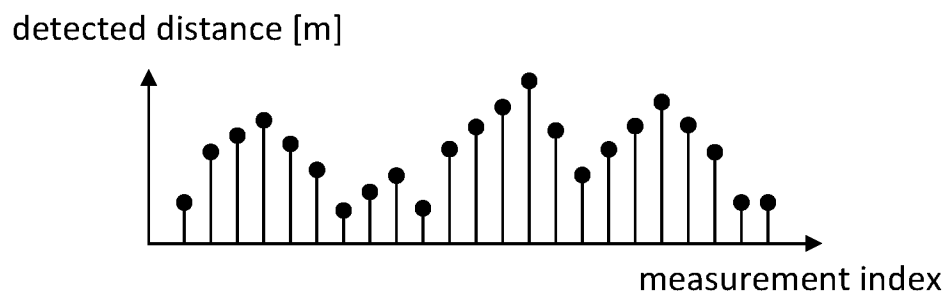


FIG. 3

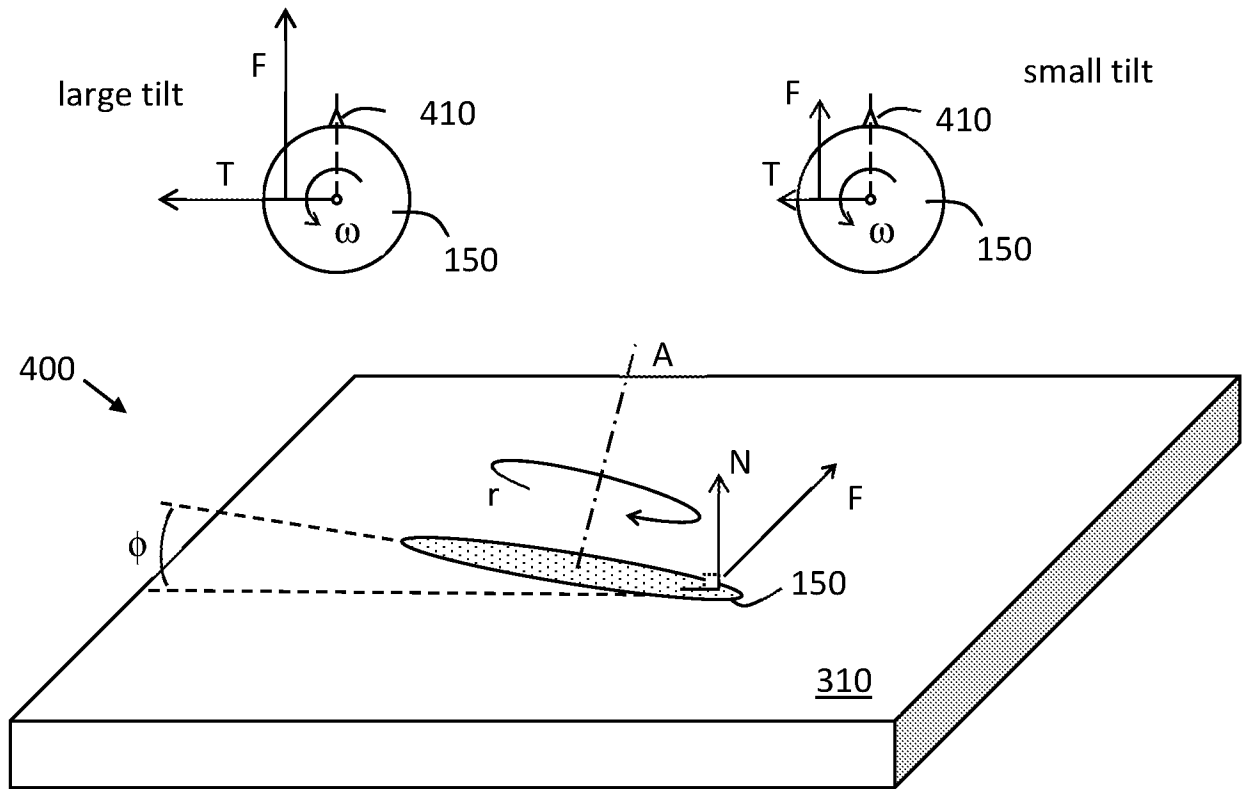


FIG. 4

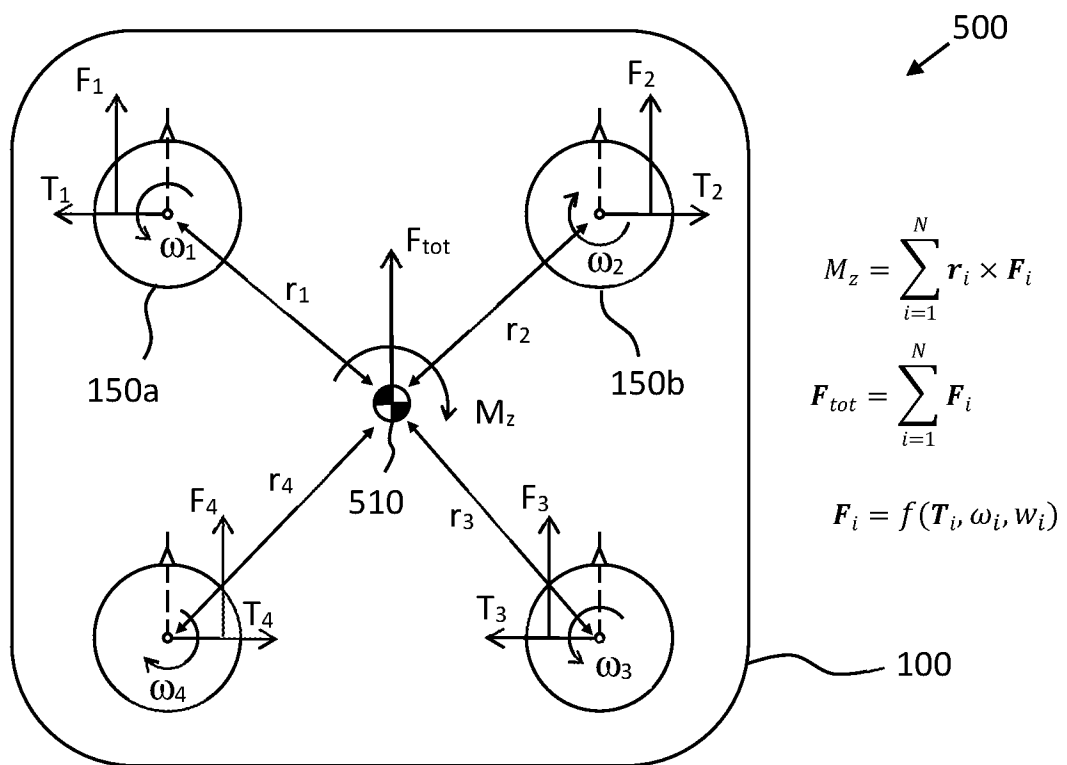


FIG. 5

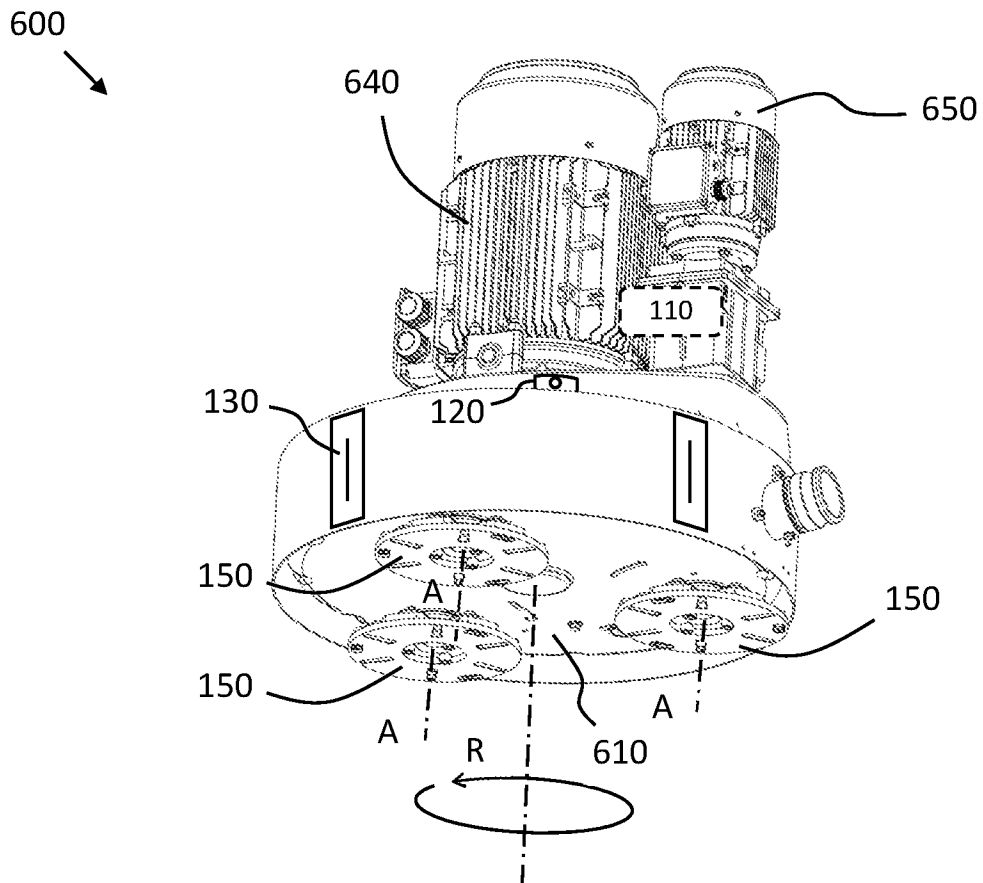


FIG. 6

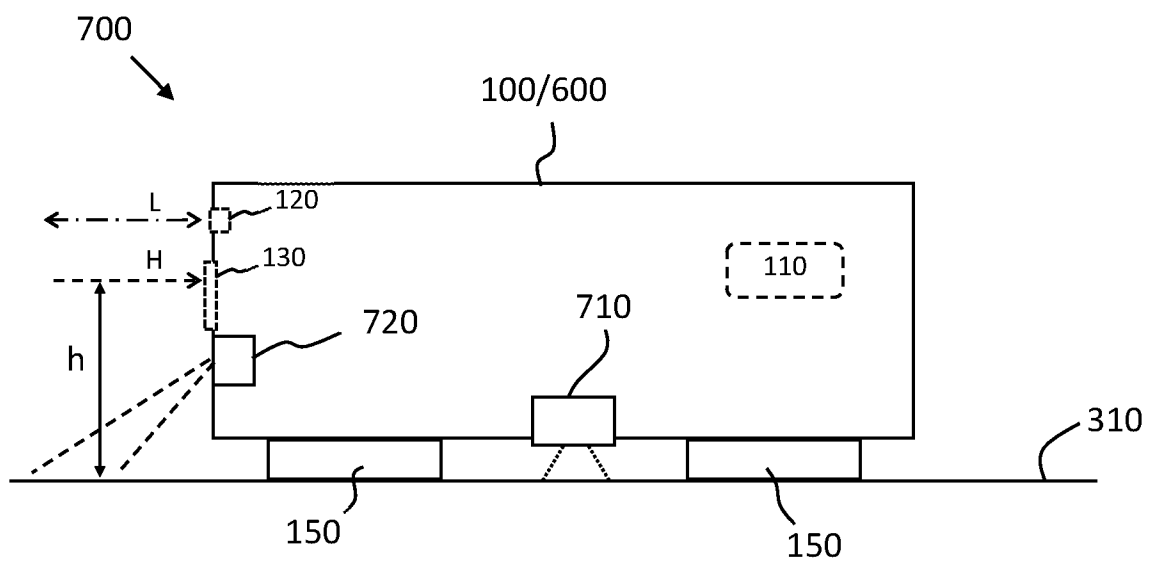


FIG. 7

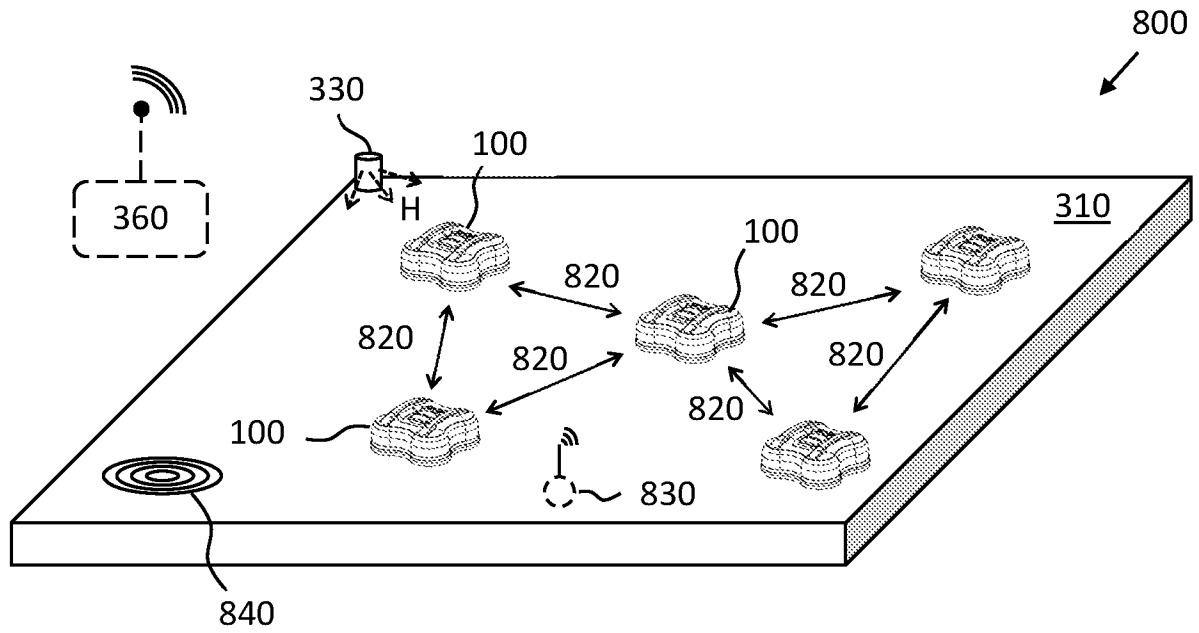


FIG. 8

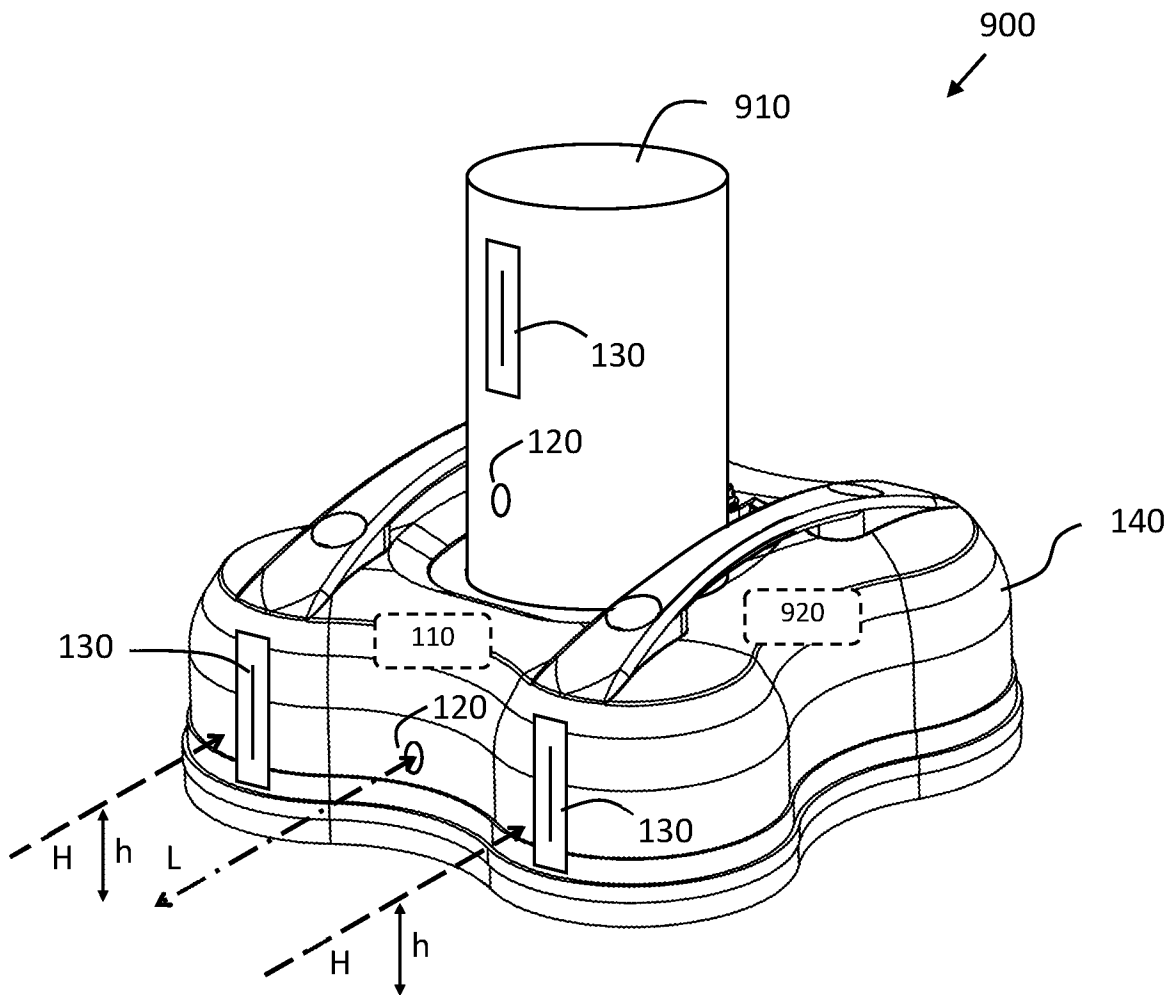


FIG. 9

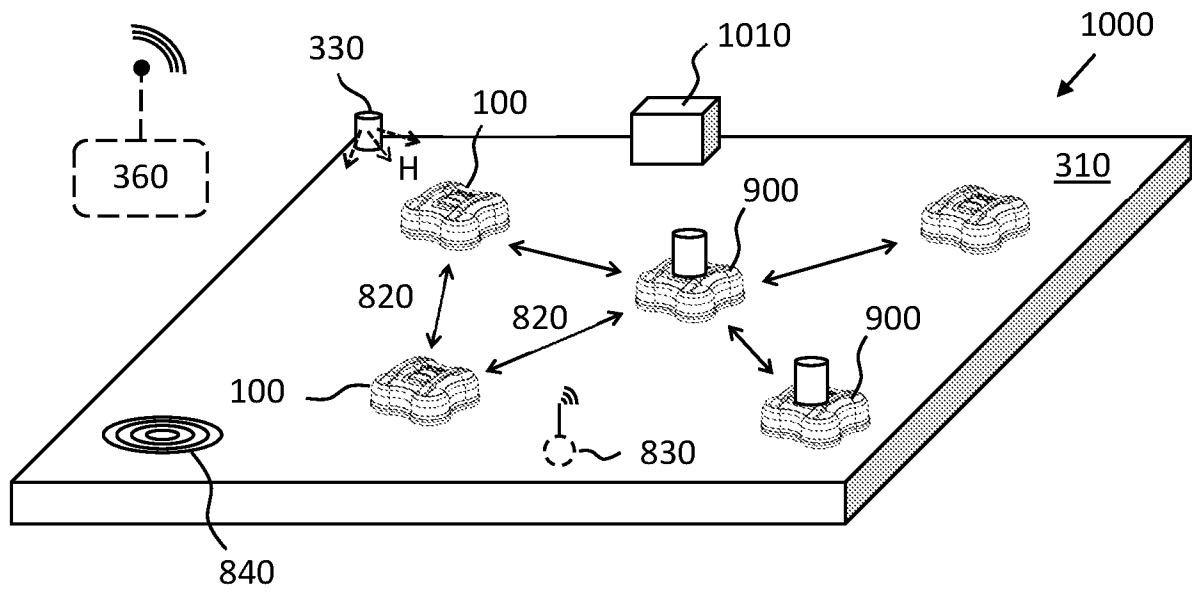


FIG. 10

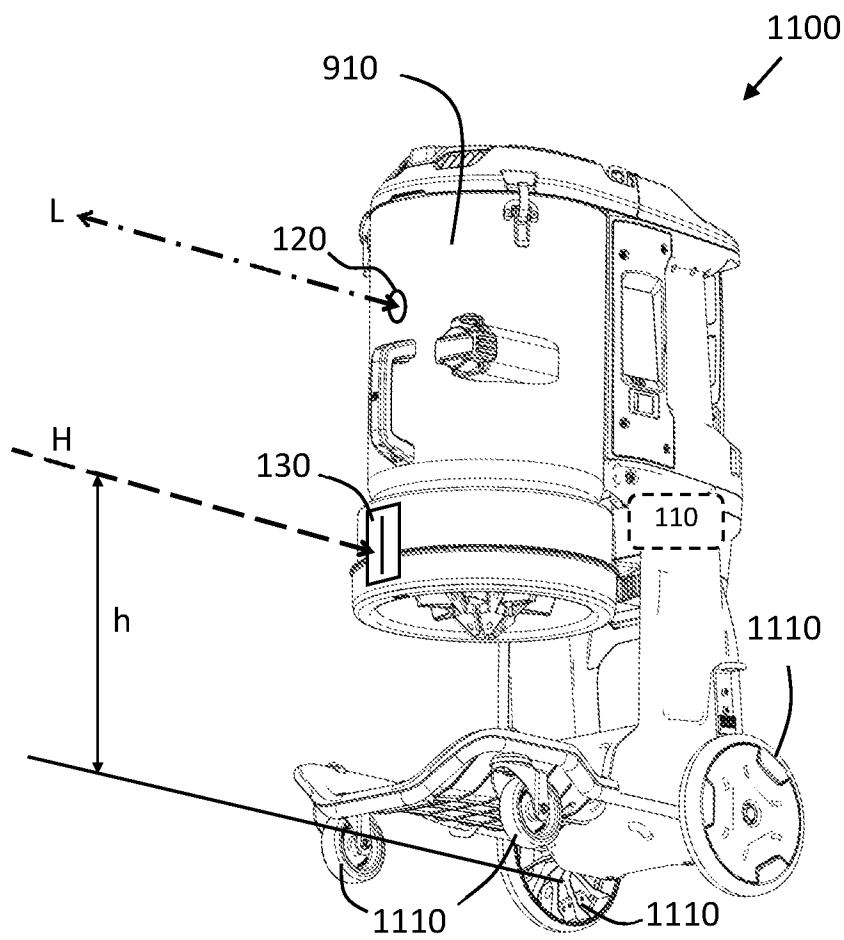


FIG. 11

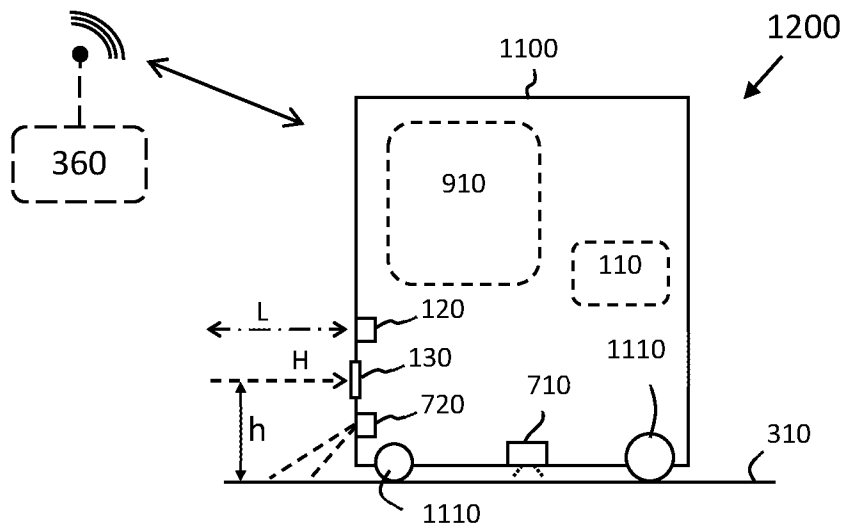


FIG. 12

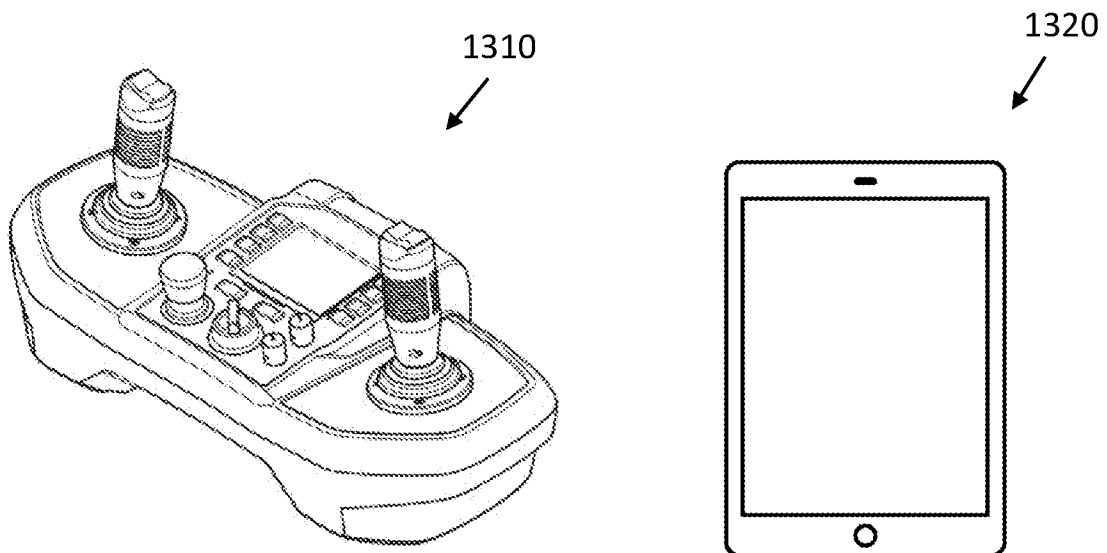


FIG. 13A

FIG. 13B

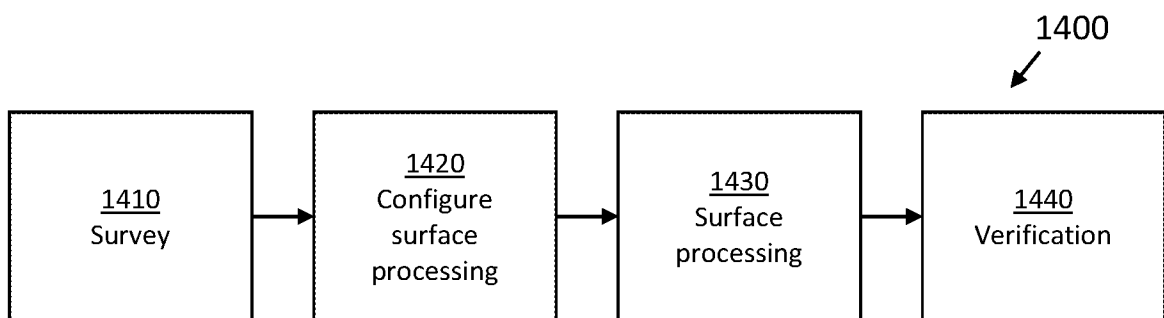


FIG. 14

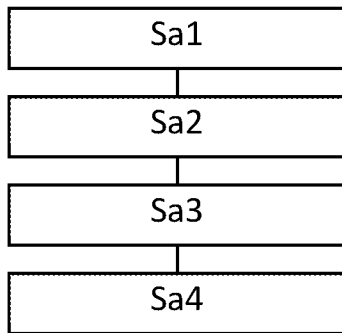


FIG. 15A

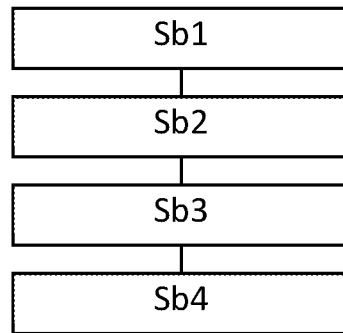


FIG. 15B

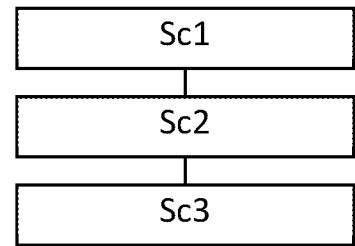


FIG. 15C

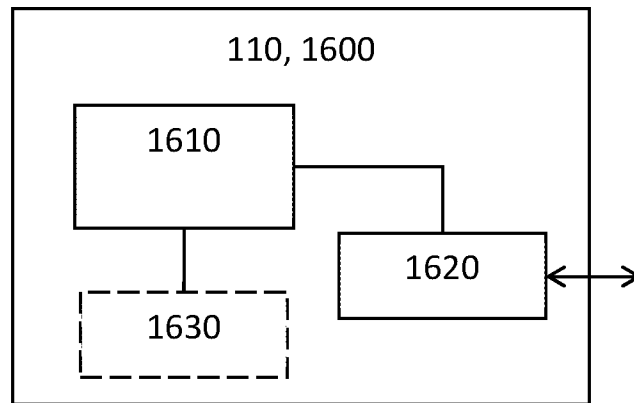


FIG. 16

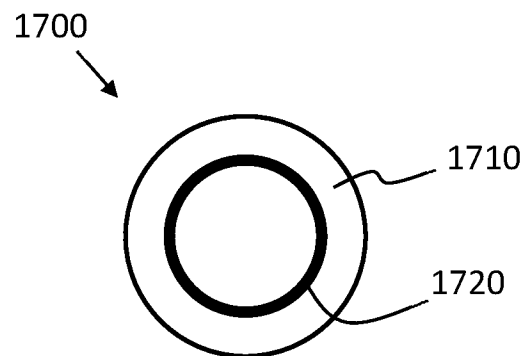


FIG. 17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2021/051275

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: B24B, E04F, G01B, G01C, G01S, G05D

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, WPI data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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D, A	--	1-16, 18-20
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A	--	1-19



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"D" document cited by the applicant in the international application	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"E" earlier application or patent but published on or after the international filing date	"&" document member of the same patent family
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

17-02-2022

Date of mailing of the international search report

17-02-2022

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INTERNATIONAL SEARCH REPORT

 International application No.
 PCT/SE2021/051275

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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Continuation of: second sheet

International Patent Classification (IPC)

E04F 21/24 (2006.01)

B24B 7/18 (2006.01)

B24B 49/12 (2006.01)

G01B 11/06 (2006.01)

G01C 15/00 (2006.01)

G01S 17/46 (2006.01)

G01S 17/89 (2020.01)

G05D 1/02 (2020.01)

INTERNATIONAL SEARCH REPORT

Information on patent family members

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