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(12) **United States Patent**
**Horn et al.**

(10) **Patent No.: US 12,385,231 B2**
(45) **Date of Patent: Aug. 12, 2025**

(54) **MEASURING SYSTEM AND CONTROLLER**

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(73) Assignee: **MOBA Mobile Automation AG**, Limburg (DE)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 621 days.

(21) Appl. No.: **17/815,138**

(22) Filed: **Jul. 26, 2022**

(65) **Prior Publication Data**

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**Related U.S. Application Data**

(63) Continuation of application No. PCT/EP2020/052497, filed on Jan. 31, 2020.

(51) **Int. Cl.**

| | |
|---|---|
| ***E02F 9/26*** | (2006.01) |
| ***E01C 19/43*** | (2006.01) |
| ***E01C 23/01*** | (2006.01) |
| ***G01B 17/00*** | (2006.01) |
| ***G01B 21/04*** | (2006.01) |

(Continued)

(52) **U.S. Cl.**

CPC ..... ***E02F 9/265*** (2013.01); ***E01C 19/43*** (2013.01); ***E01C 23/01*** (2013.01); ***G01B 17/00*** (2013.01); ***G01B 21/045*** (2013.01); ***G01B 21/047*** (2013.01); ***G01B 21/08*** (2013.01); *G01B 21/22* (2013.01)

(58) **Field of Classification Search**

CPC ..... E02F 9/265; E01C 19/43; E01C 23/01; G01B 17/00; G01B 21/045; G01B 21/047; G01B 21/08; G01B 21/22

USPC ..... 404/84.05–84.5, 118

See application file for complete search history.

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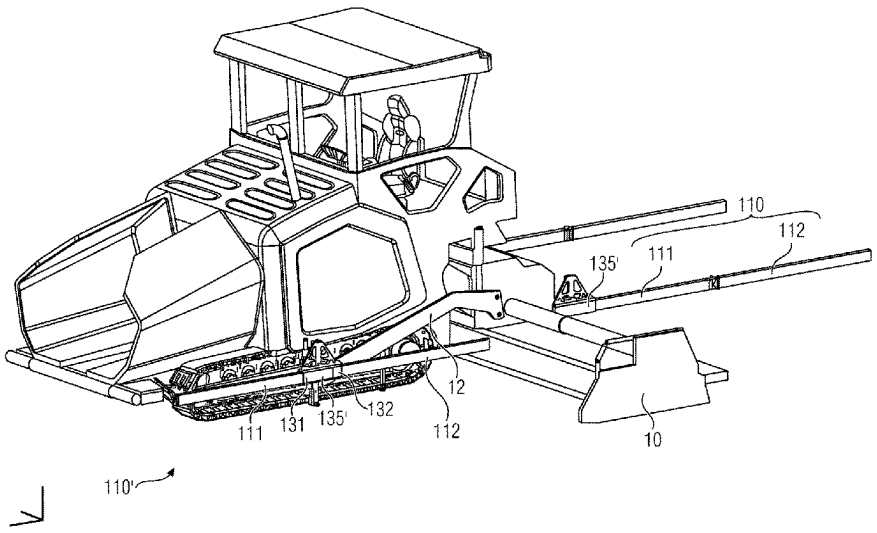
*Primary Examiner* — Raymond W Addie

(74) *Attorney, Agent, or Firm* — PERKINS COIE LLP; Michael A. Glenn

(57) **ABSTRACT**

The invention relates to a measuring system for a construction machine having a carrier including several portions, a measuring system for a construction machine including a calculation unit determining a regression line as well as a controller having two control loops.

**27 Claims, 35 Drawing Sheets**



(51) **Int. Cl.**
***G01B 21/08*** (2006.01)
*G01B 21/22* (2006.01)

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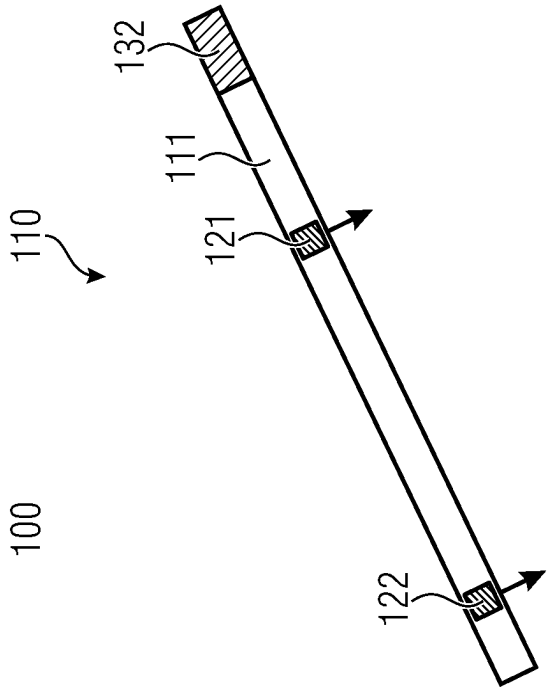



Fig. 1a

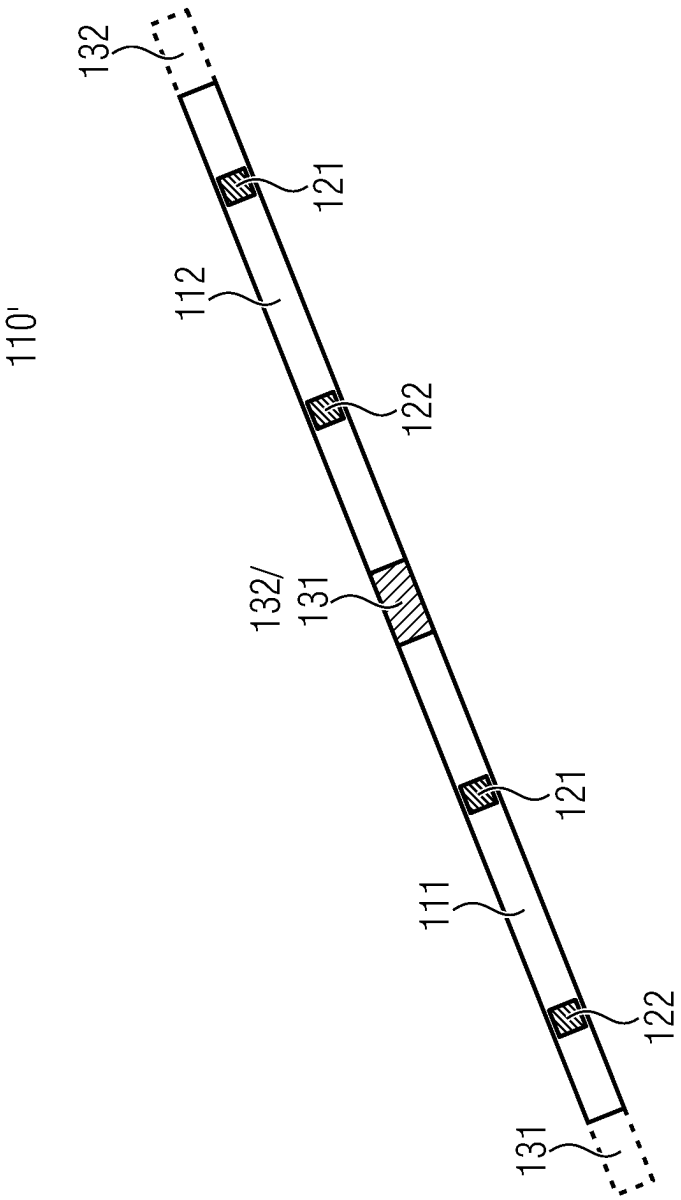
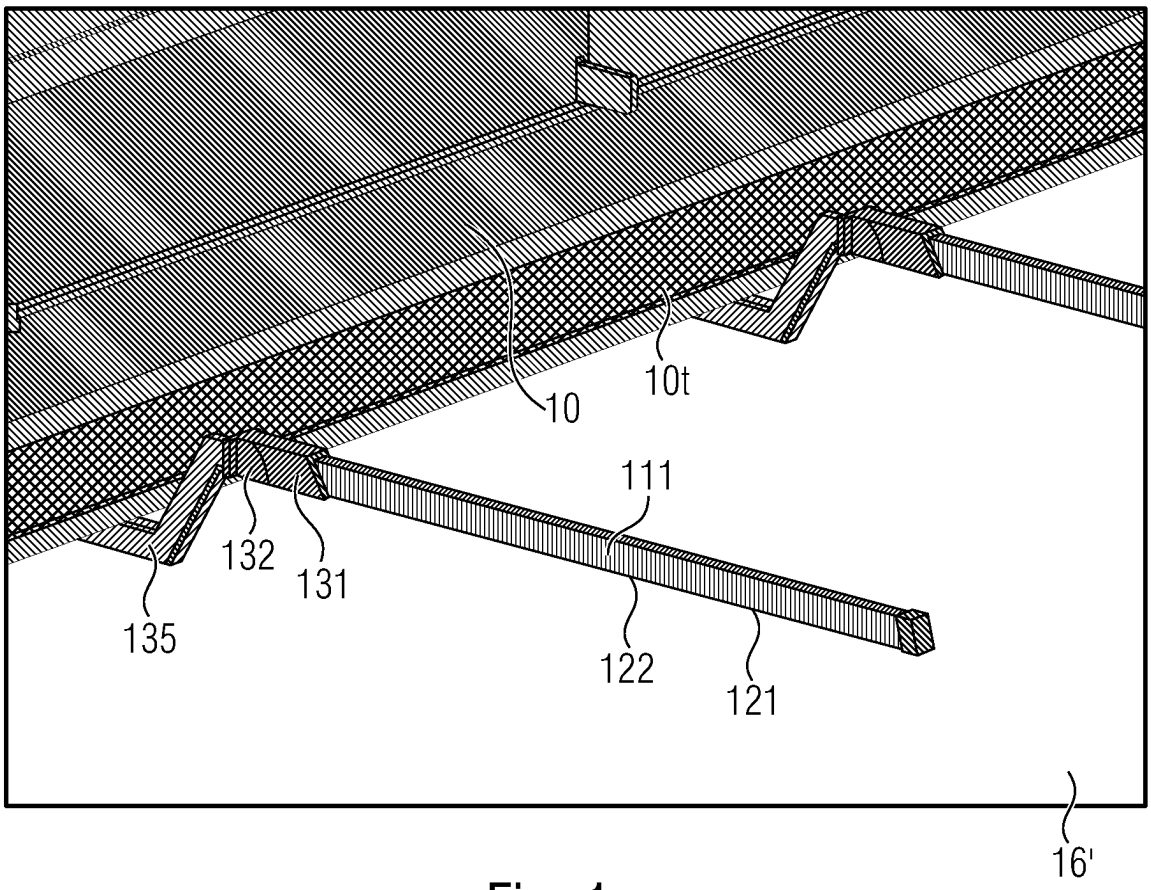



Fig. 1b

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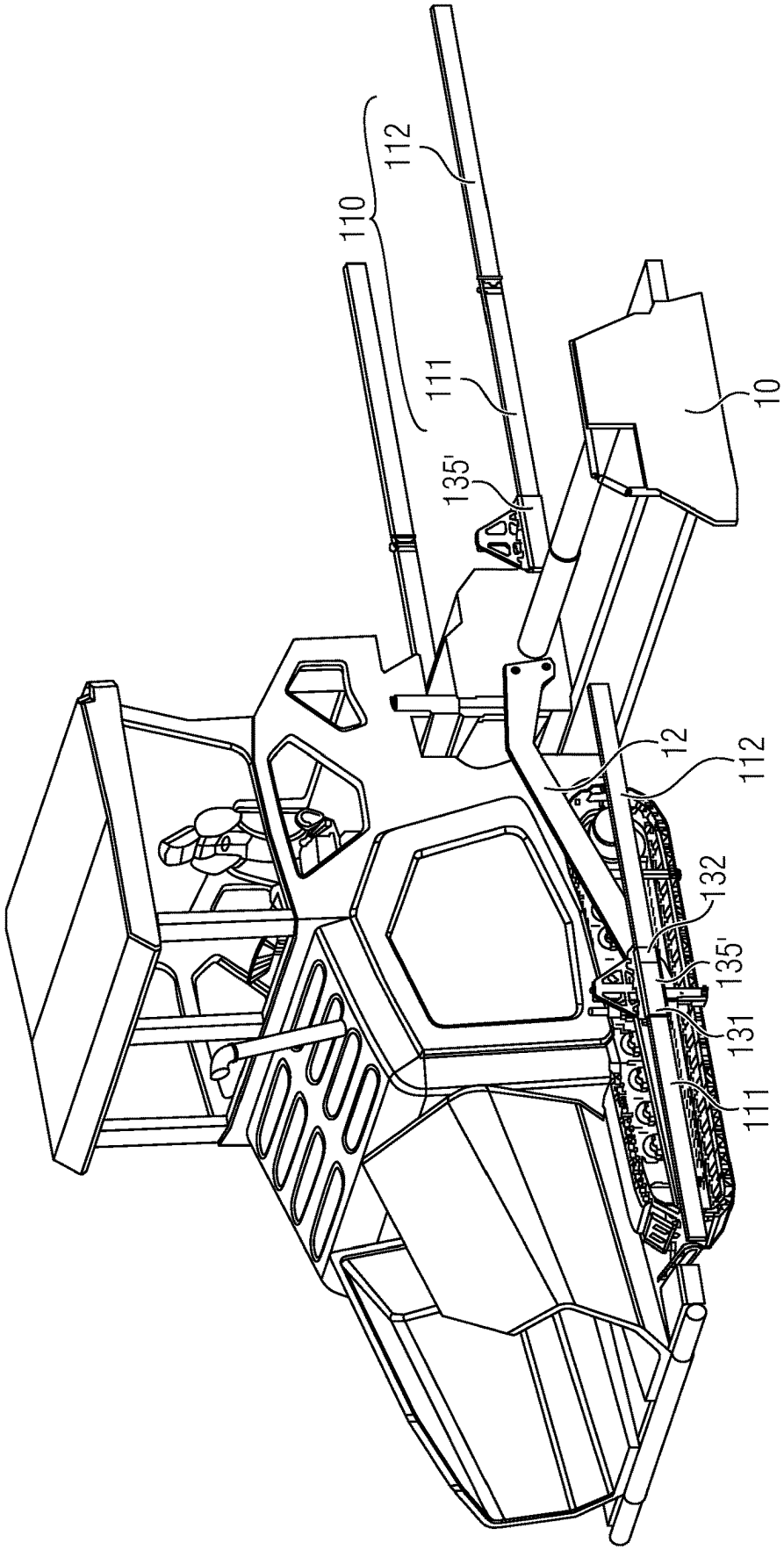


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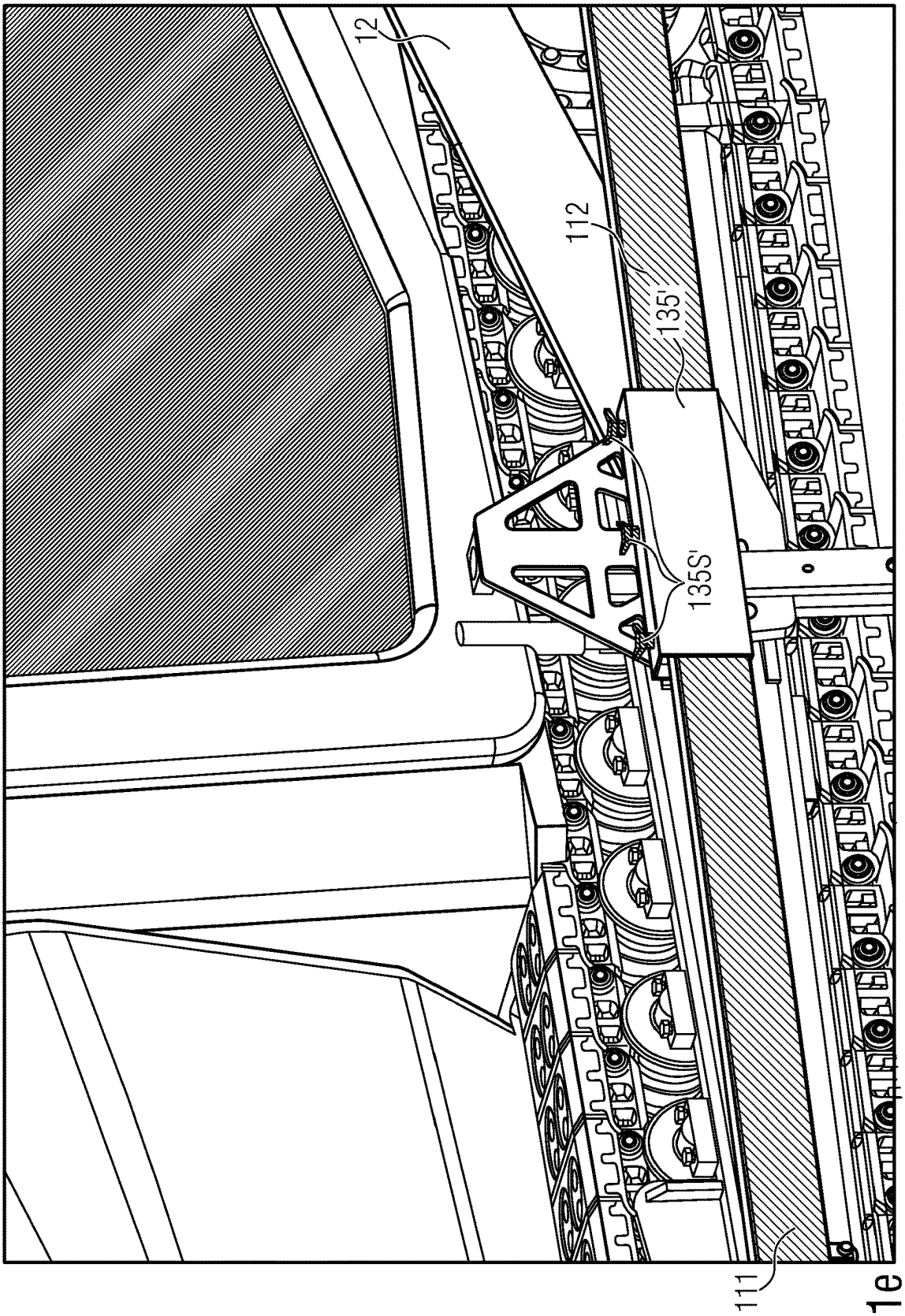
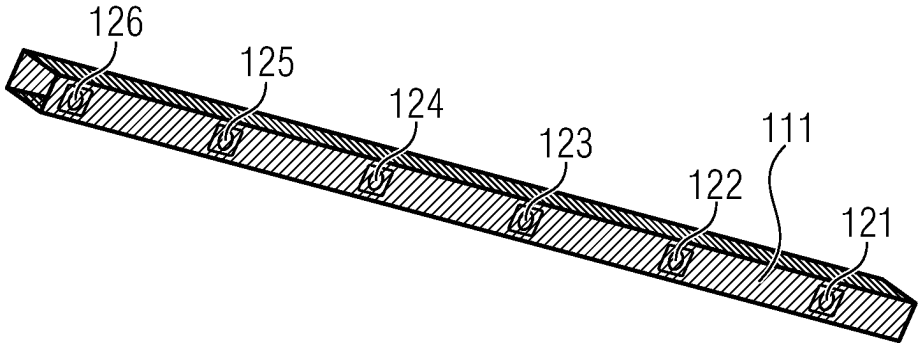



Fig. 1e

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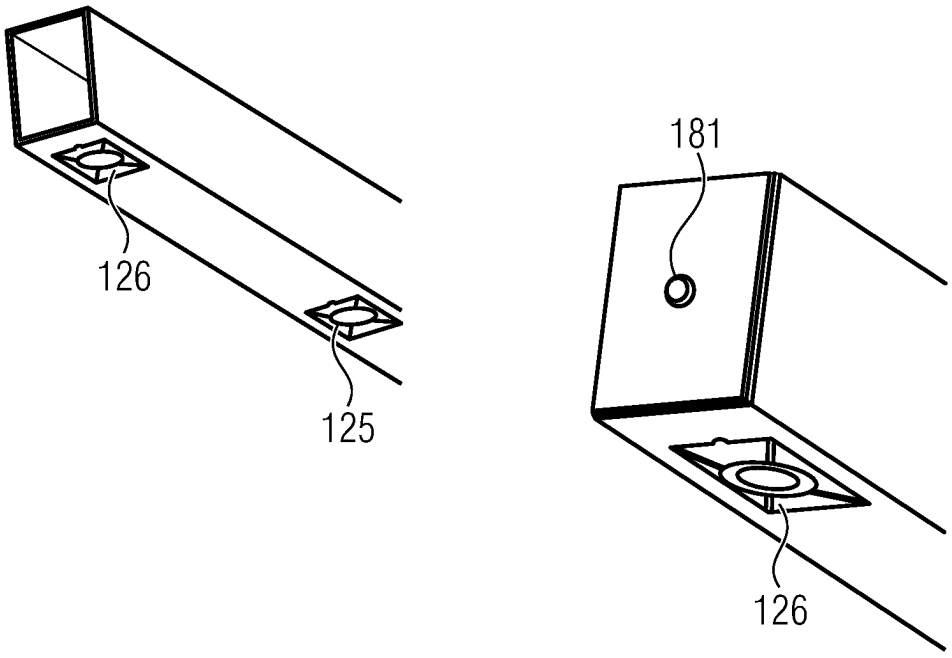
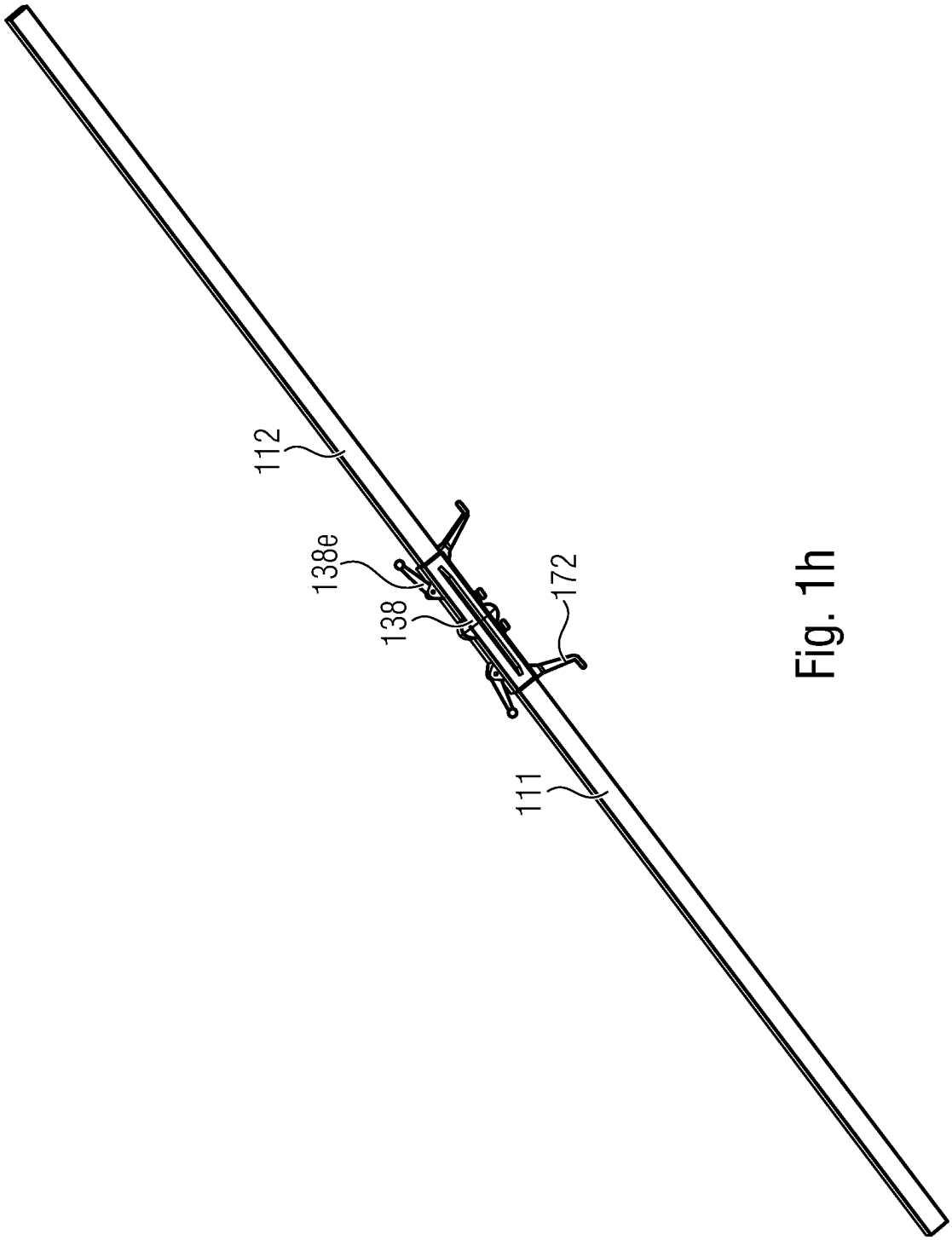



Fig. 1g

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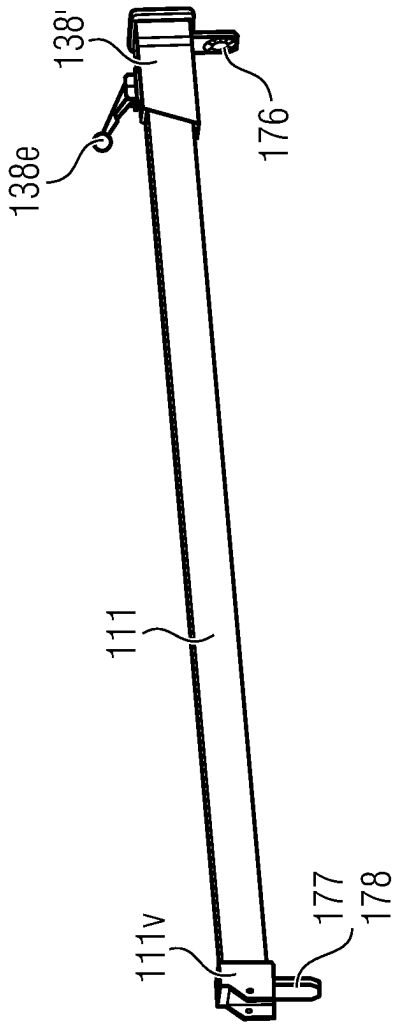



Fig. 1i

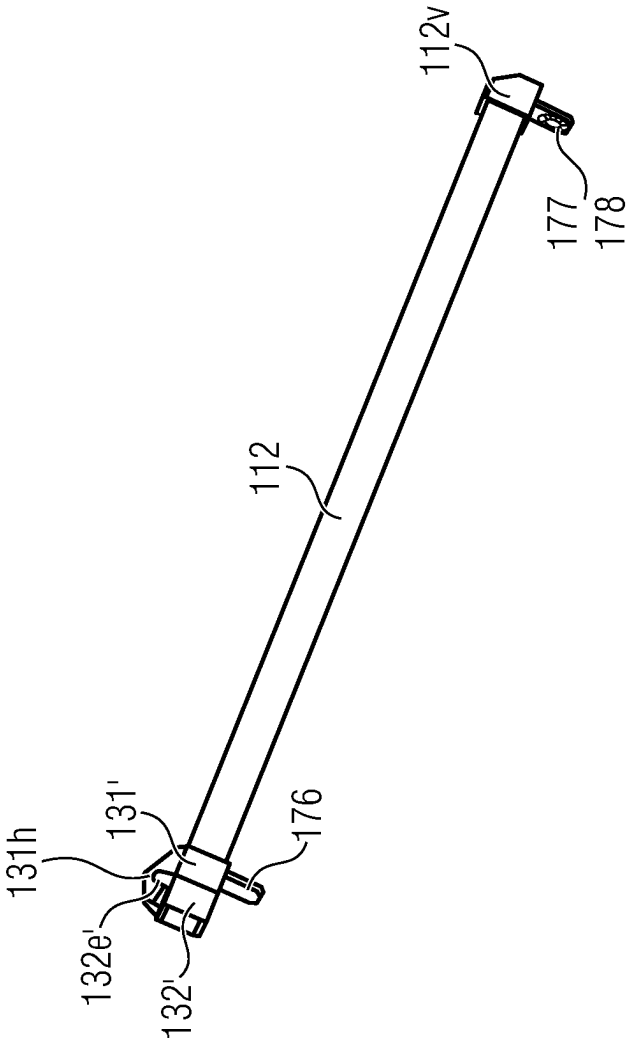



Fig. 1j

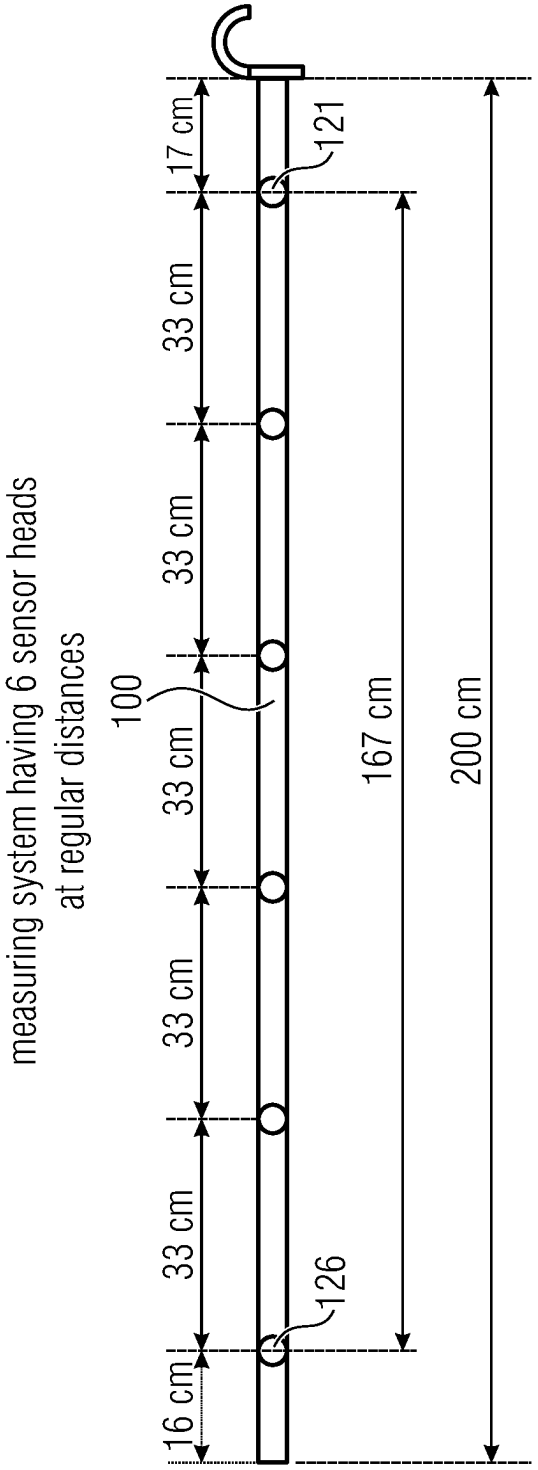

measuring system having 6 sensor heads
at regular distances
17 cm
33 cm
33 cm
33 cm
33 cm
16 cm
100
121
126
167 cm
200 cm

Fig. 1k

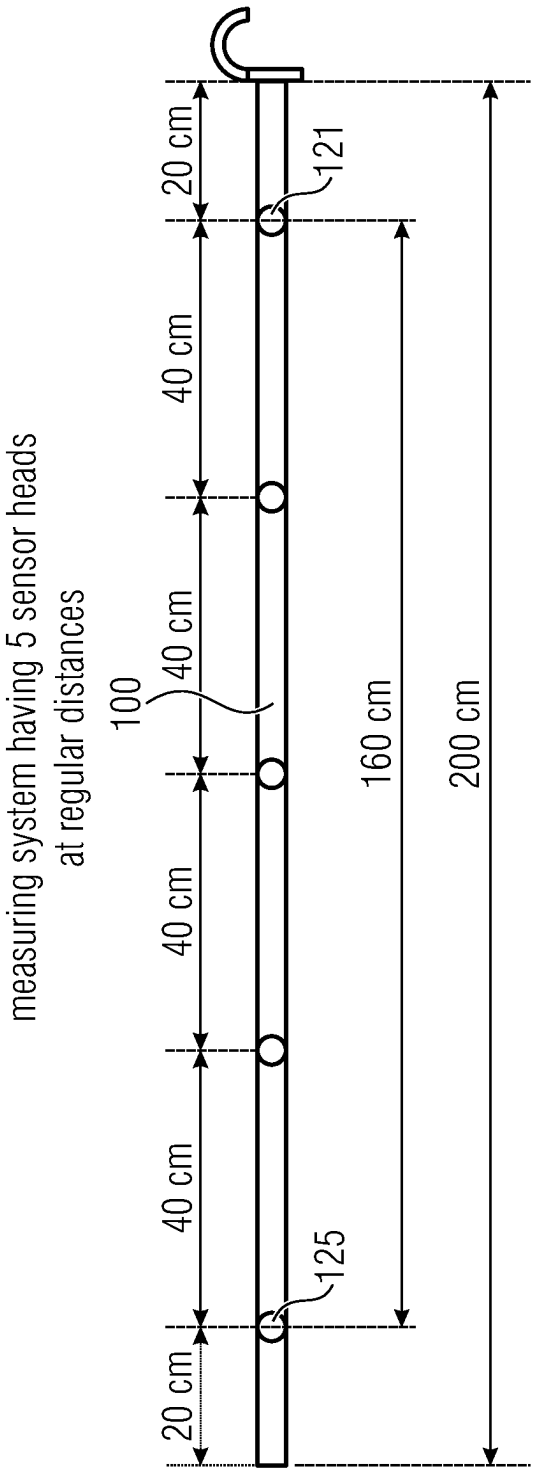

measuring system having 5 sensor heads
at regular distances
20 cm
40 cm
40 cm
40 cm
20 cm
100
121
125
160 cm
200 cm

Fig. 1l

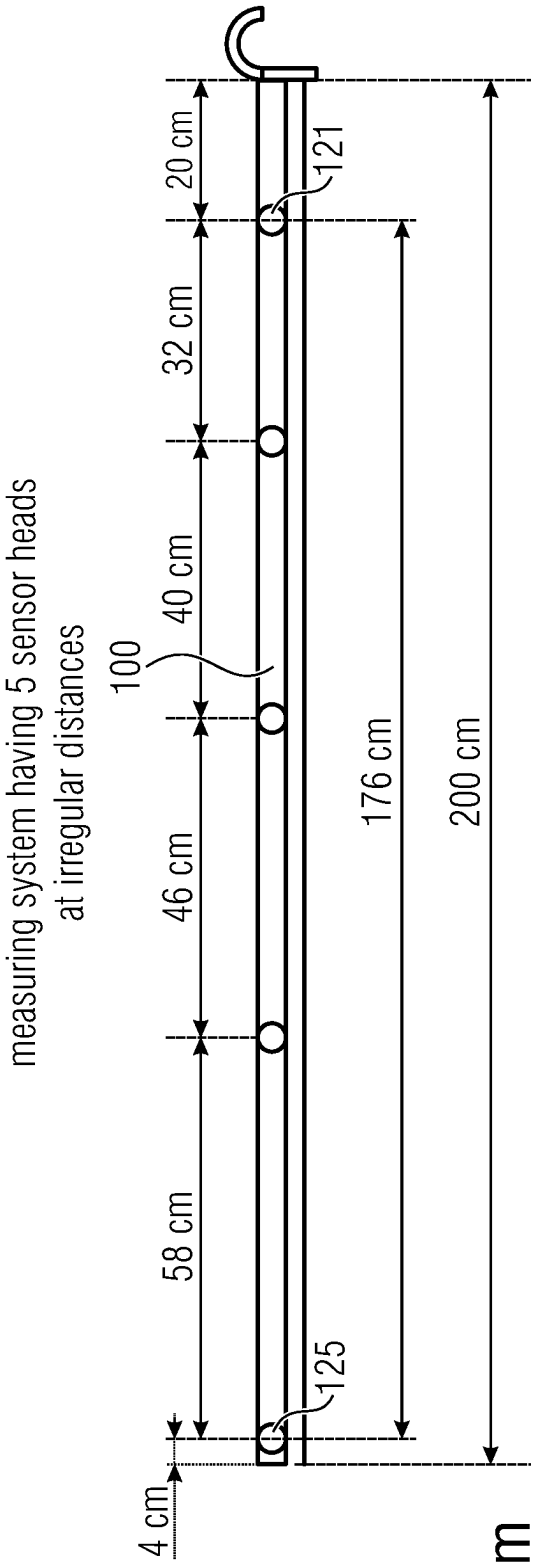

measuring system having 5 sensor heads
at irregular distances
100
20 cm
32 cm
40 cm
46 cm
58 cm
4 cm
121
125
176 cm
200 cm

Fig. 1m

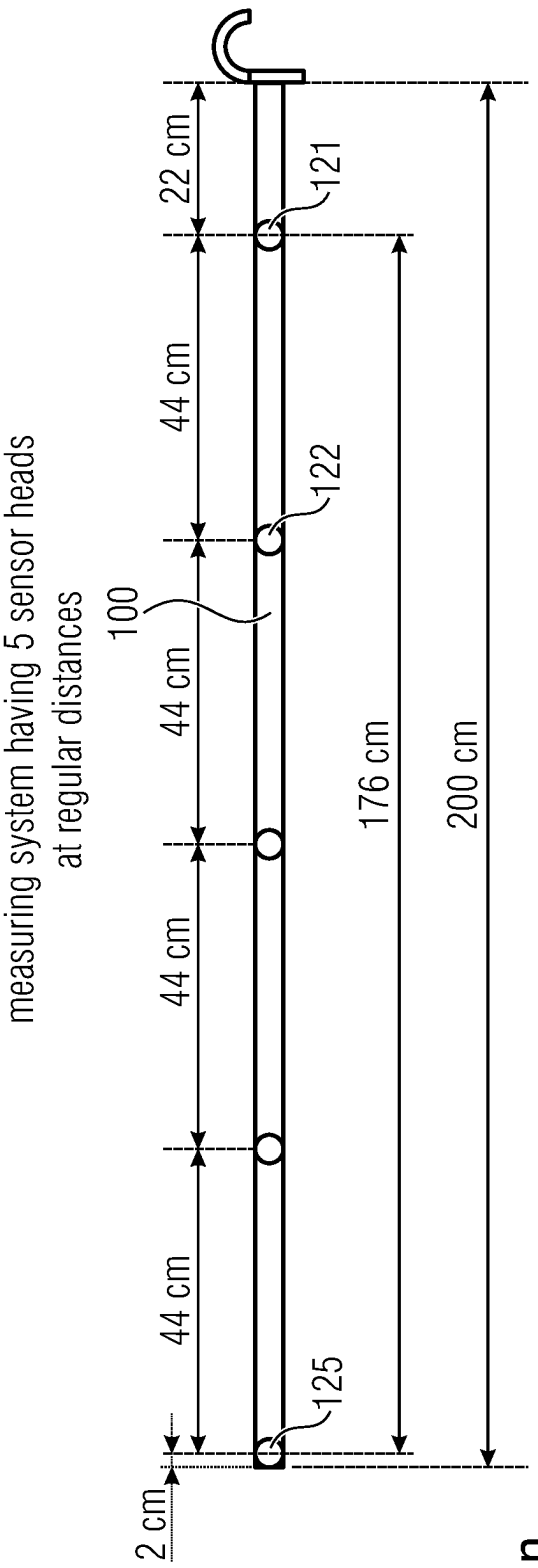

measuring system having 5 sensor heads
at regular distances
100
22 cm
44 cm
44 cm
44 cm
44 cm
2 cm
121
122
125
176 cm
200 cm

Fig. 1n

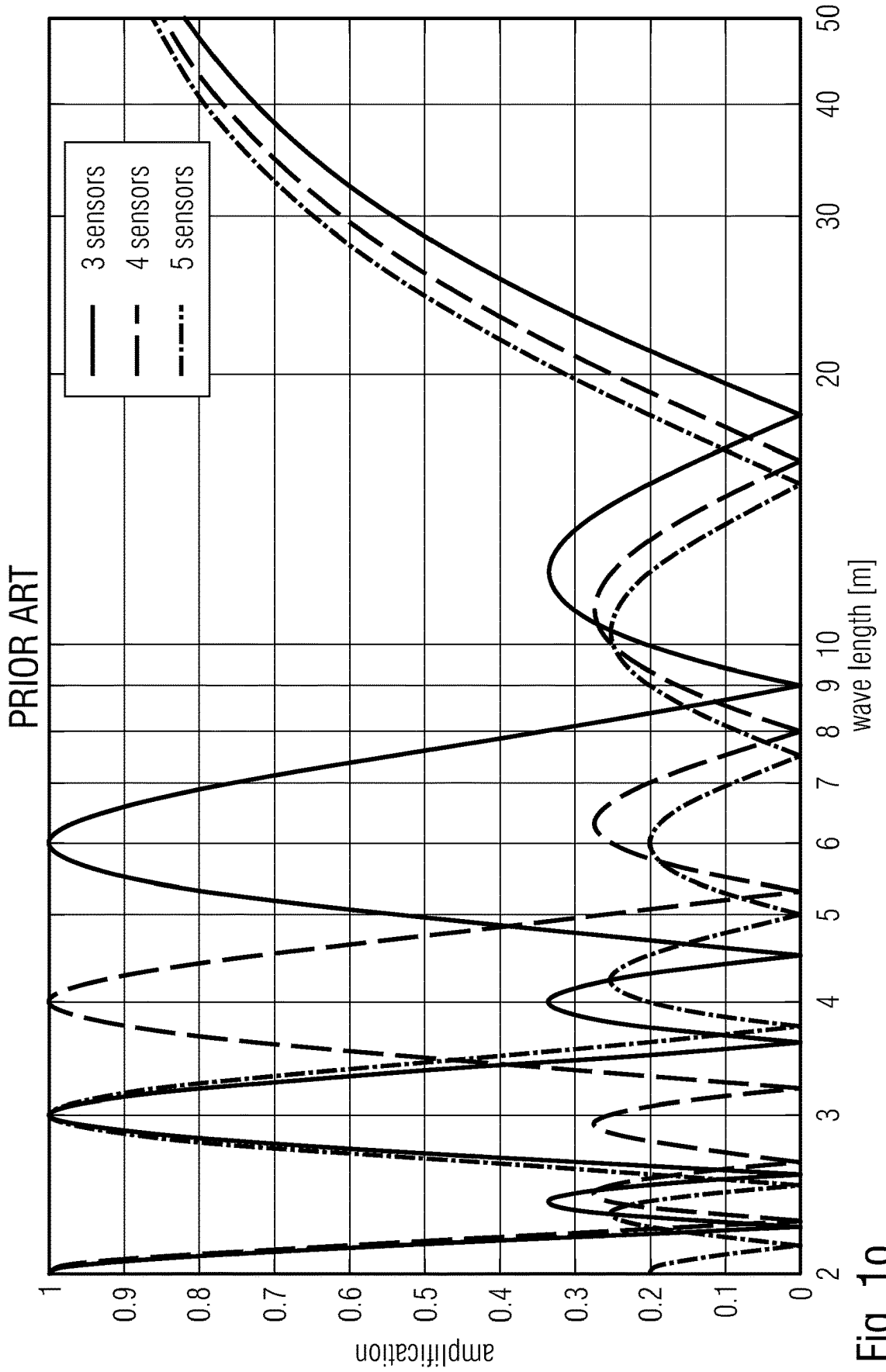

PRIOR ART
3 sensors
4 sensors
5 sensors
amplification
wave length [m]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
6
7
8
9
10
20
30
40
50

Fig. 1o

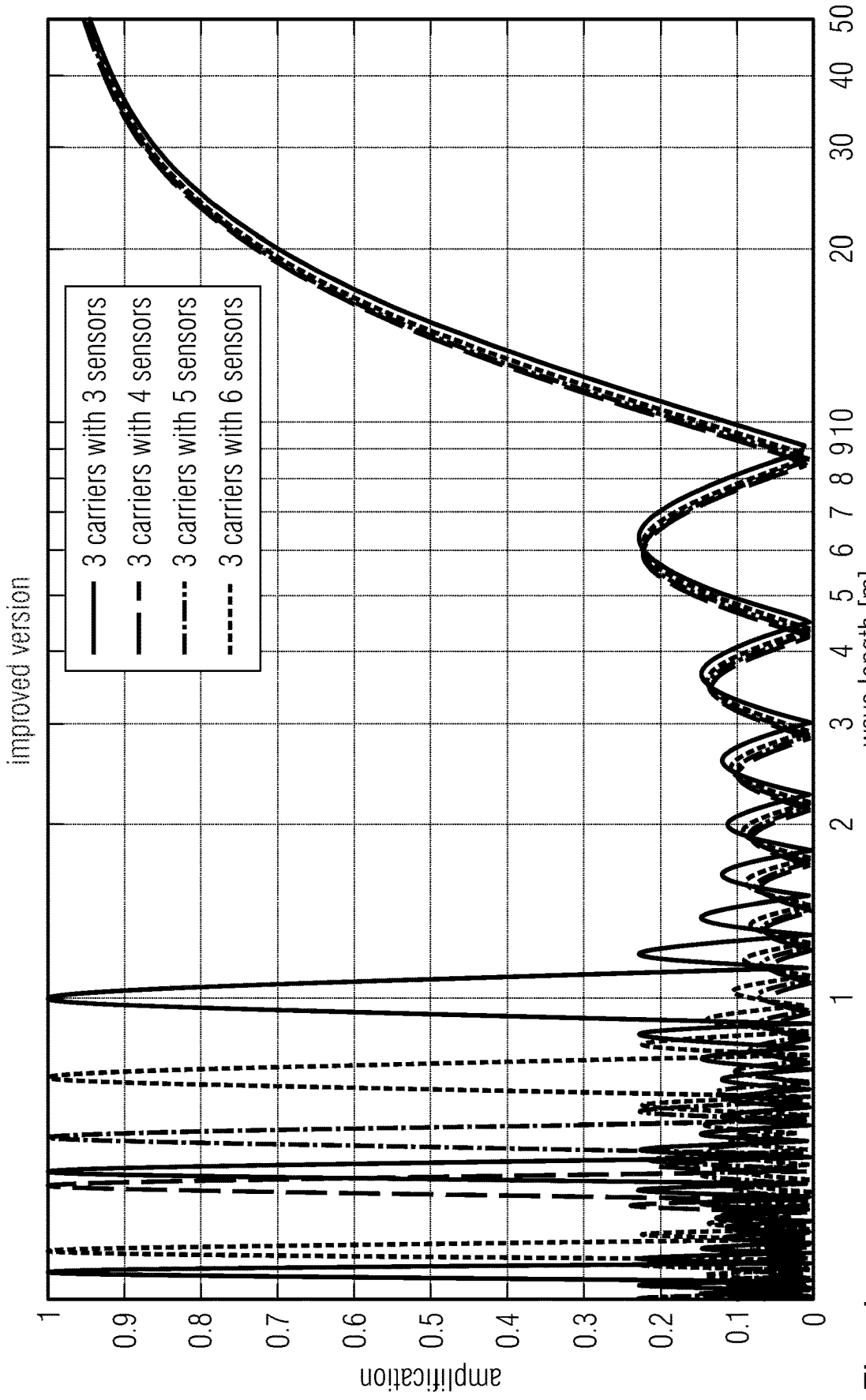

improved version
3 carriers with 3 sensors
3 carriers with 4 sensors
3 carriers with 5 sensors
3 carriers with 6 sensors
amplification
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
wave length [m]
1
2
3
4
5
6
7
8
9
10
20
30
40
50

Fig. 1p

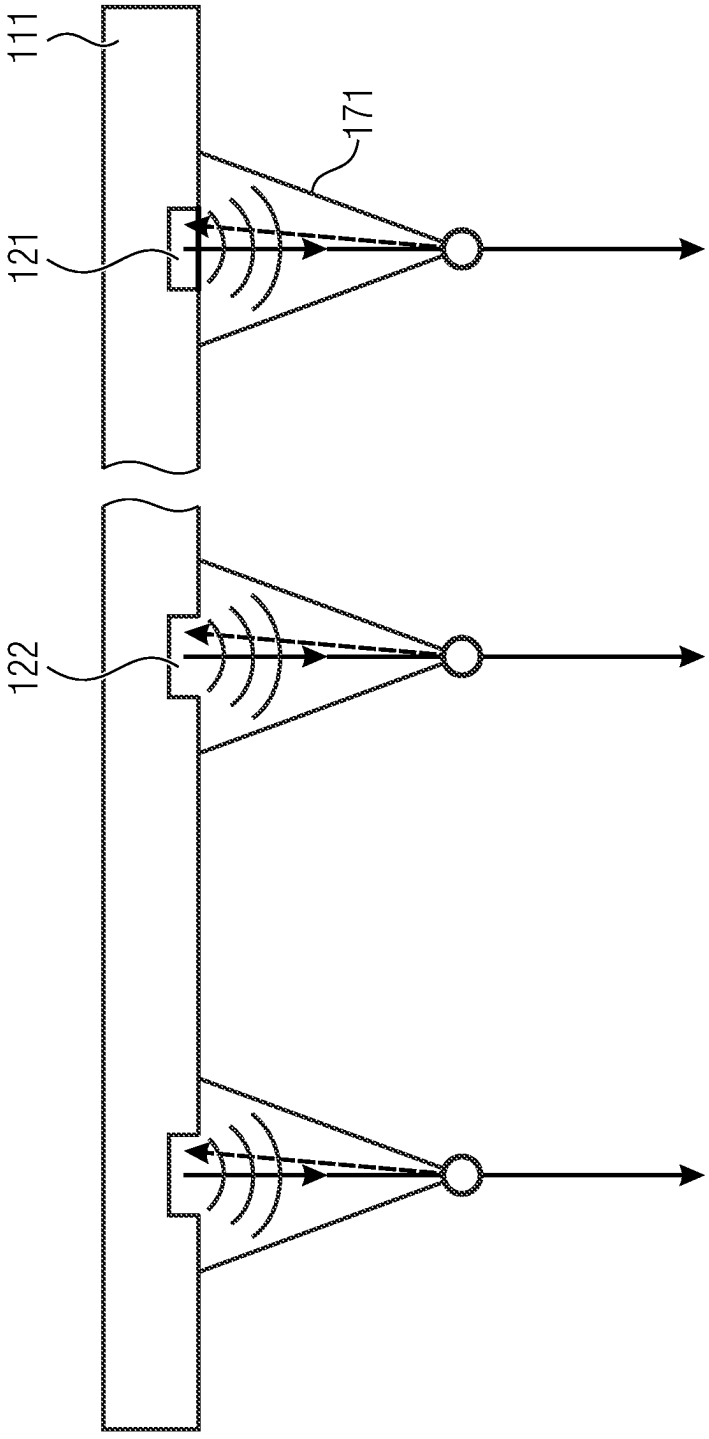



Fig. 1q

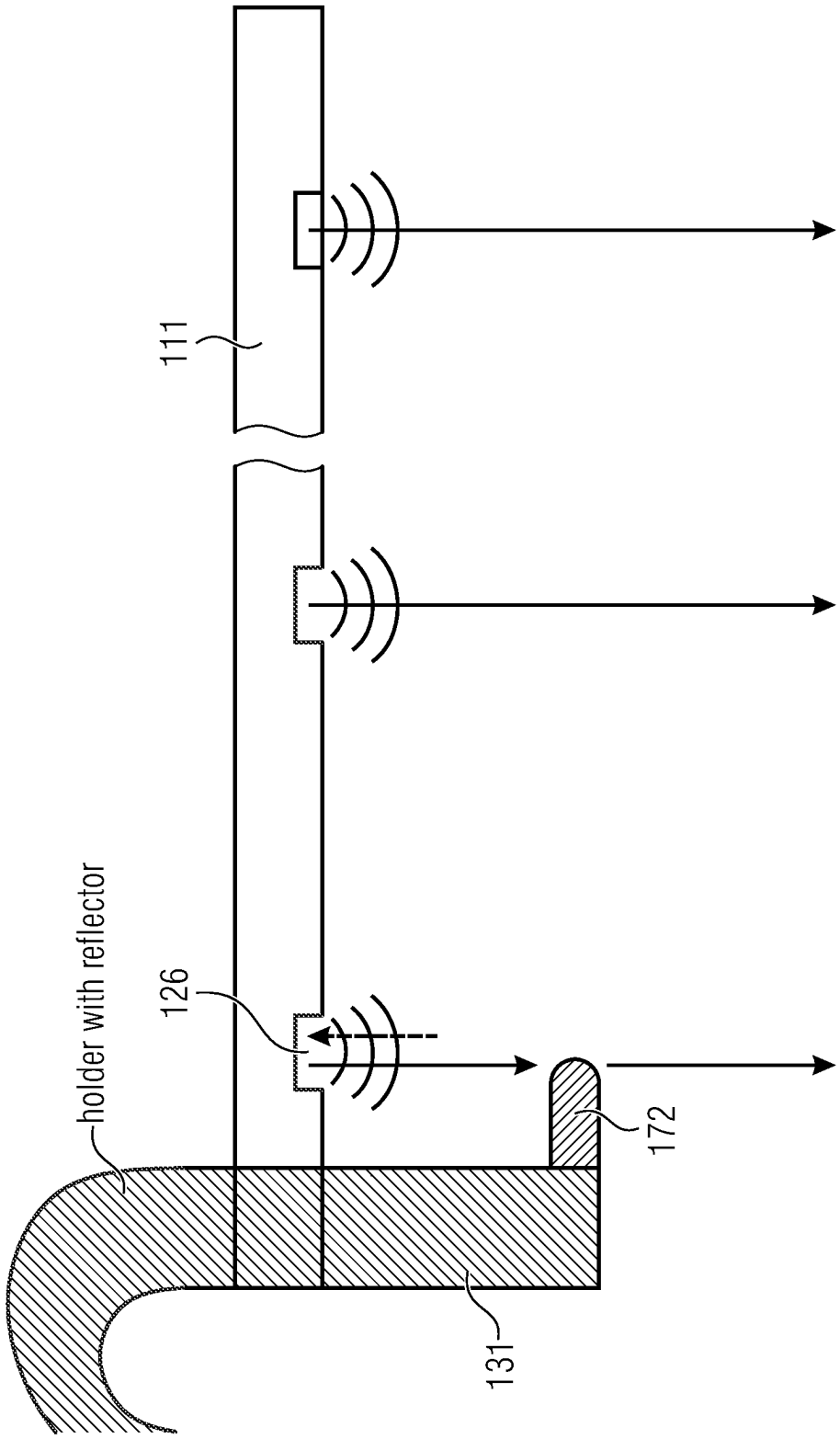
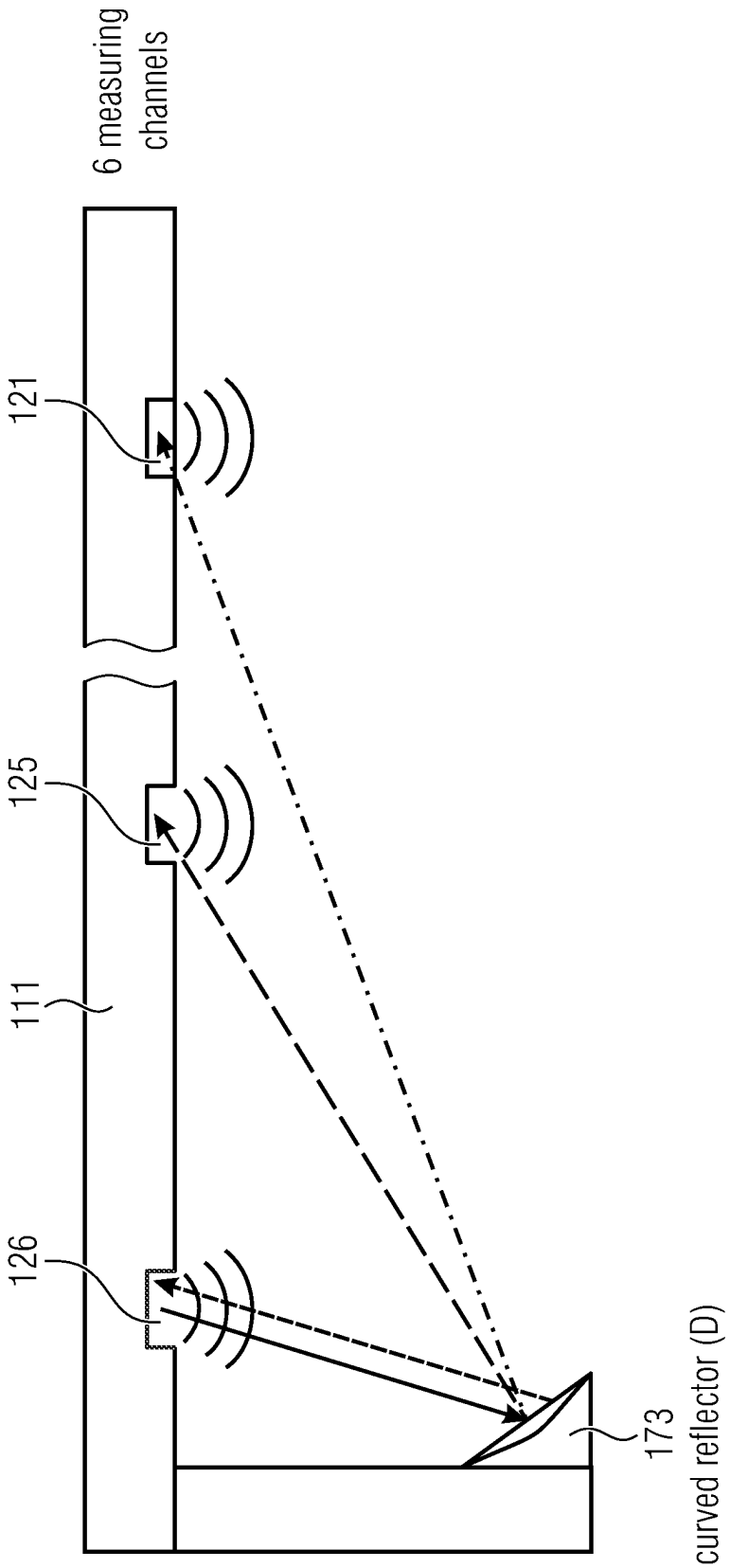



Fig. 1r

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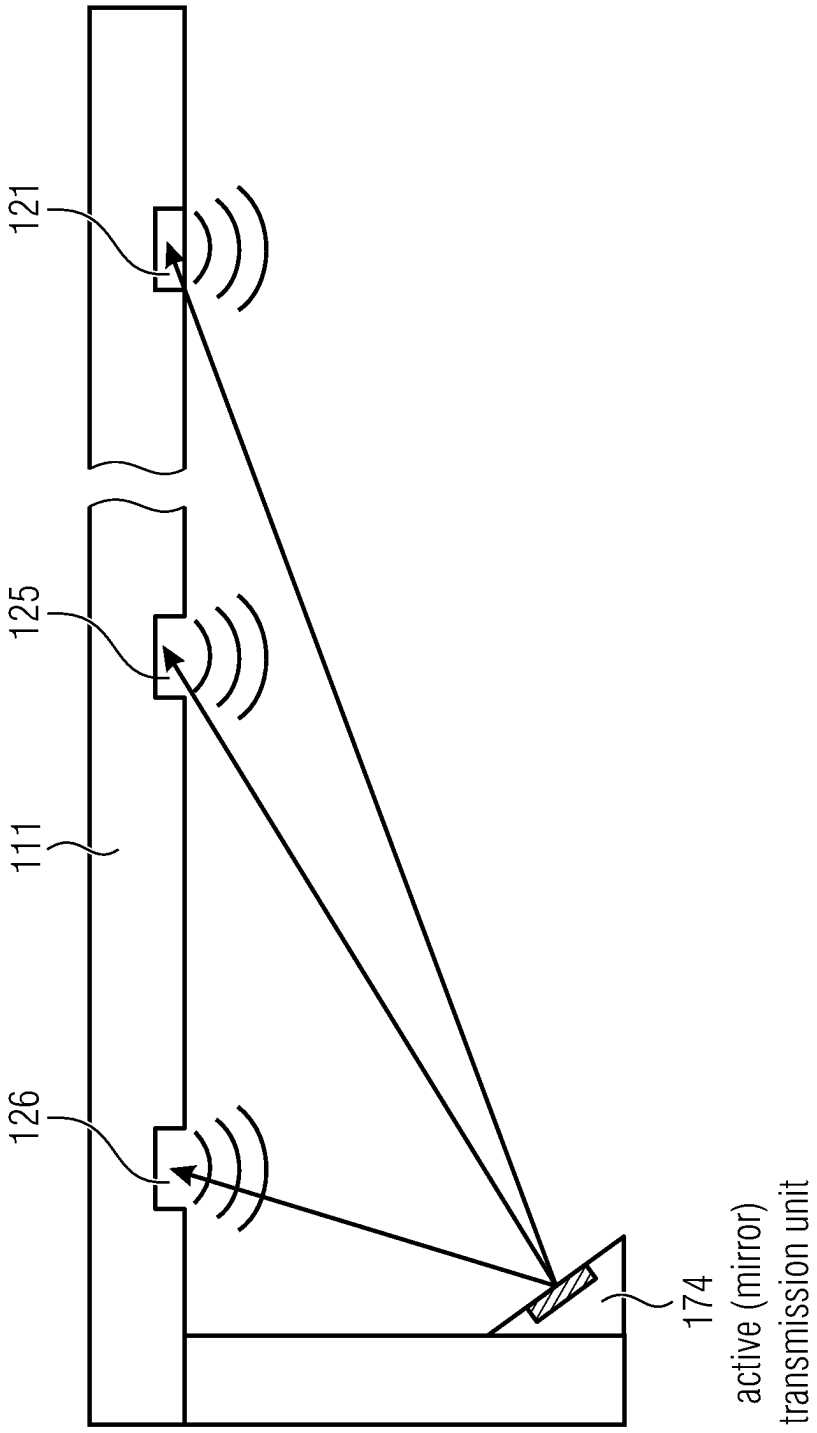



Fig. 1t

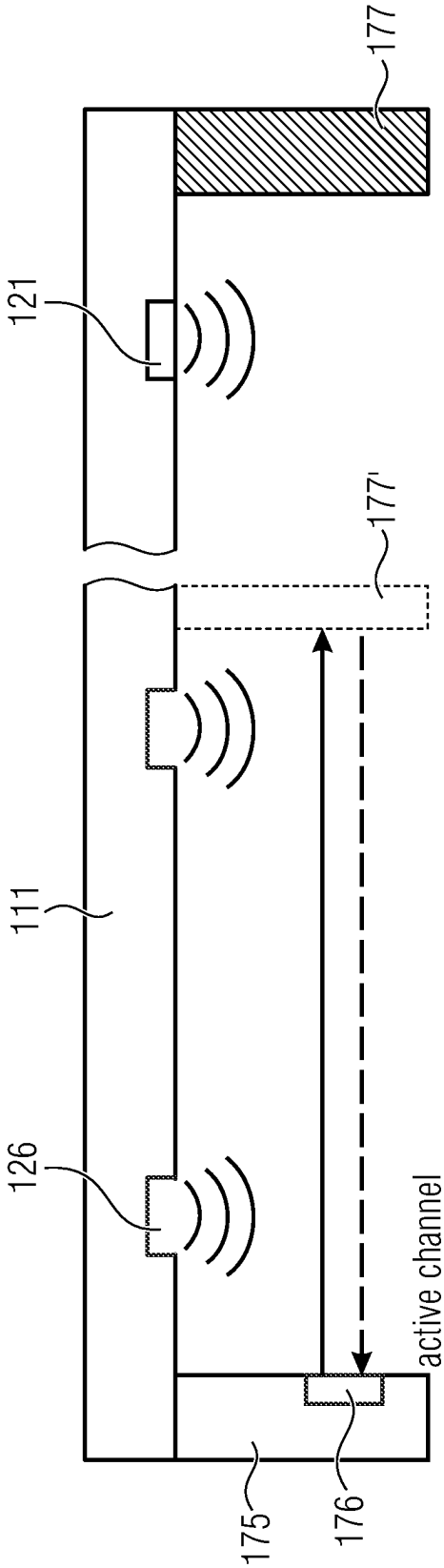



Fig. 1u

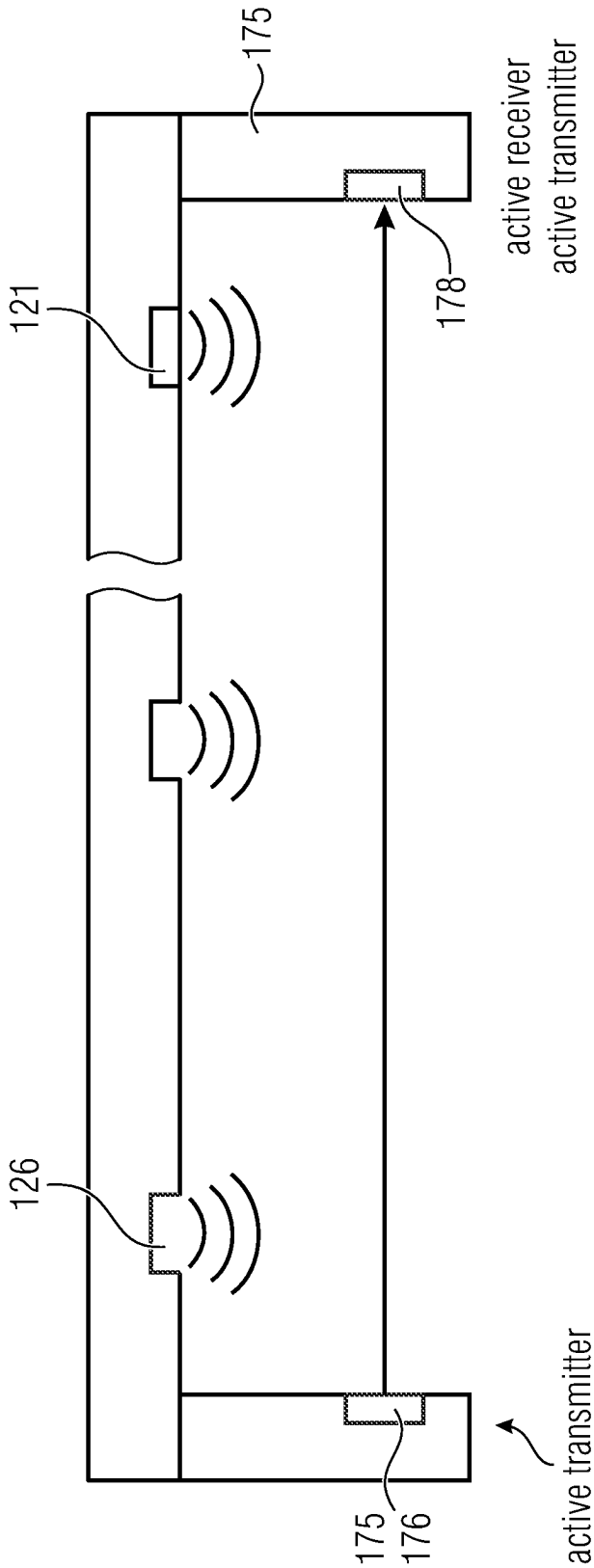

175
active receiver
active transmitter
178
121
126
175
176
active transmitter
active receiver

Fig. 1v

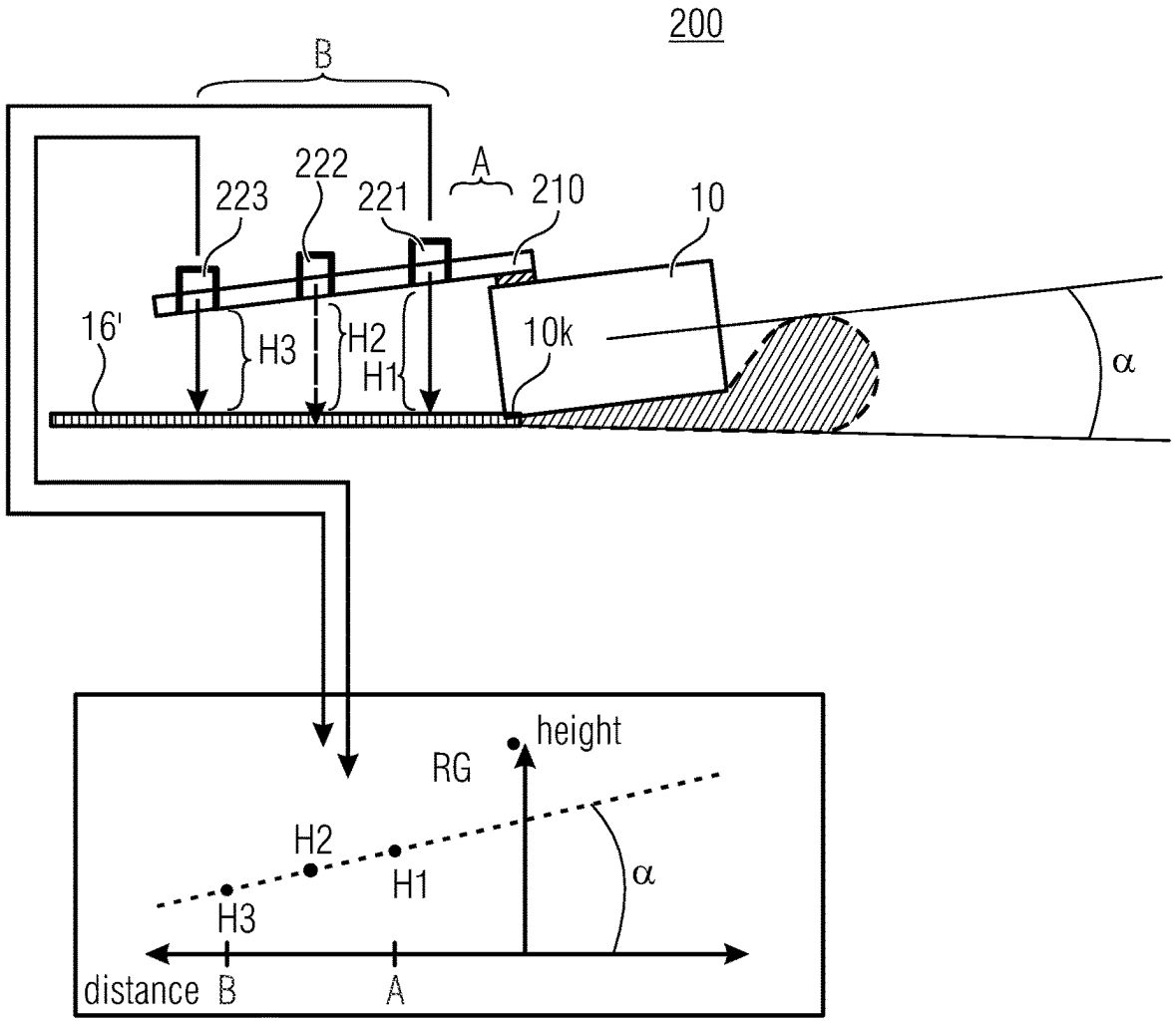

200
B
223
222
221
A
210
10
16'
H3
H2
H1
10k
α
height
RG
H2
H1
H3
α
distance
B
A

Fig. 2a

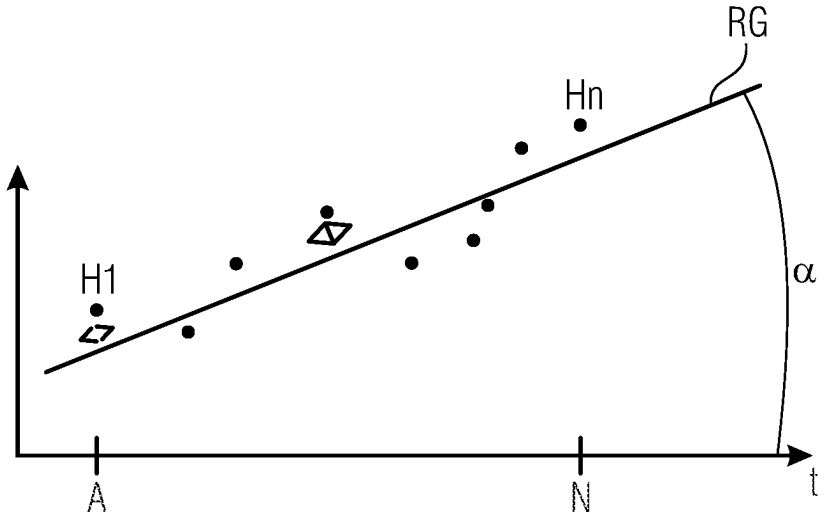
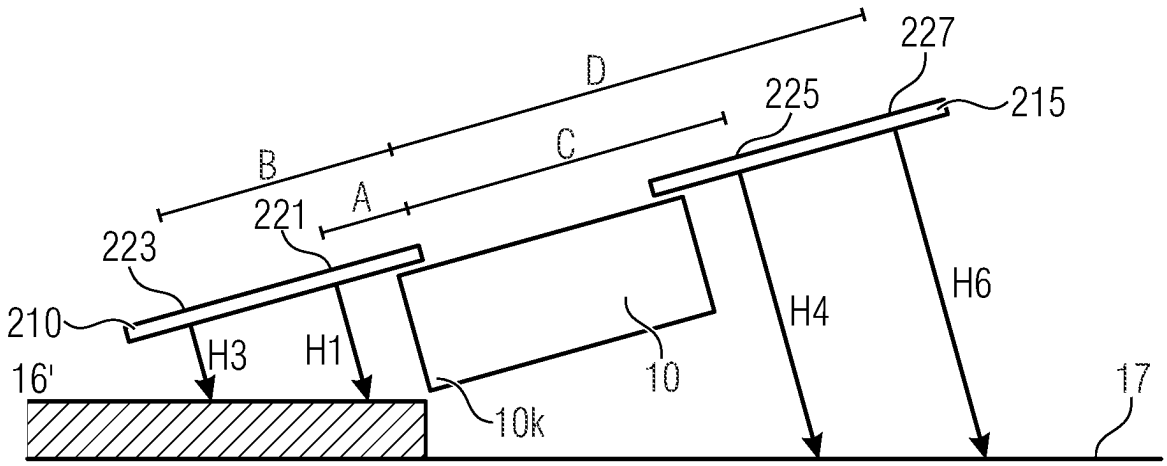



Fig. 2b

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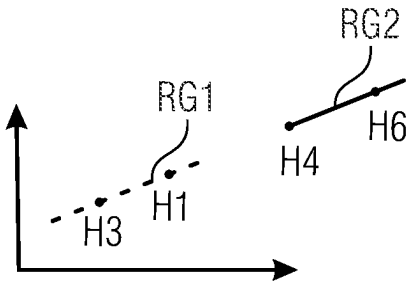


Fig. 2d

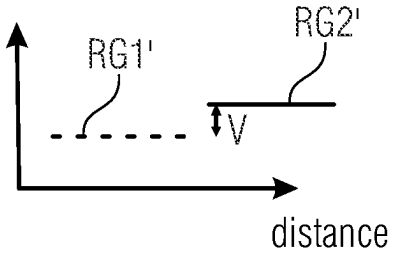


Fig. 2e

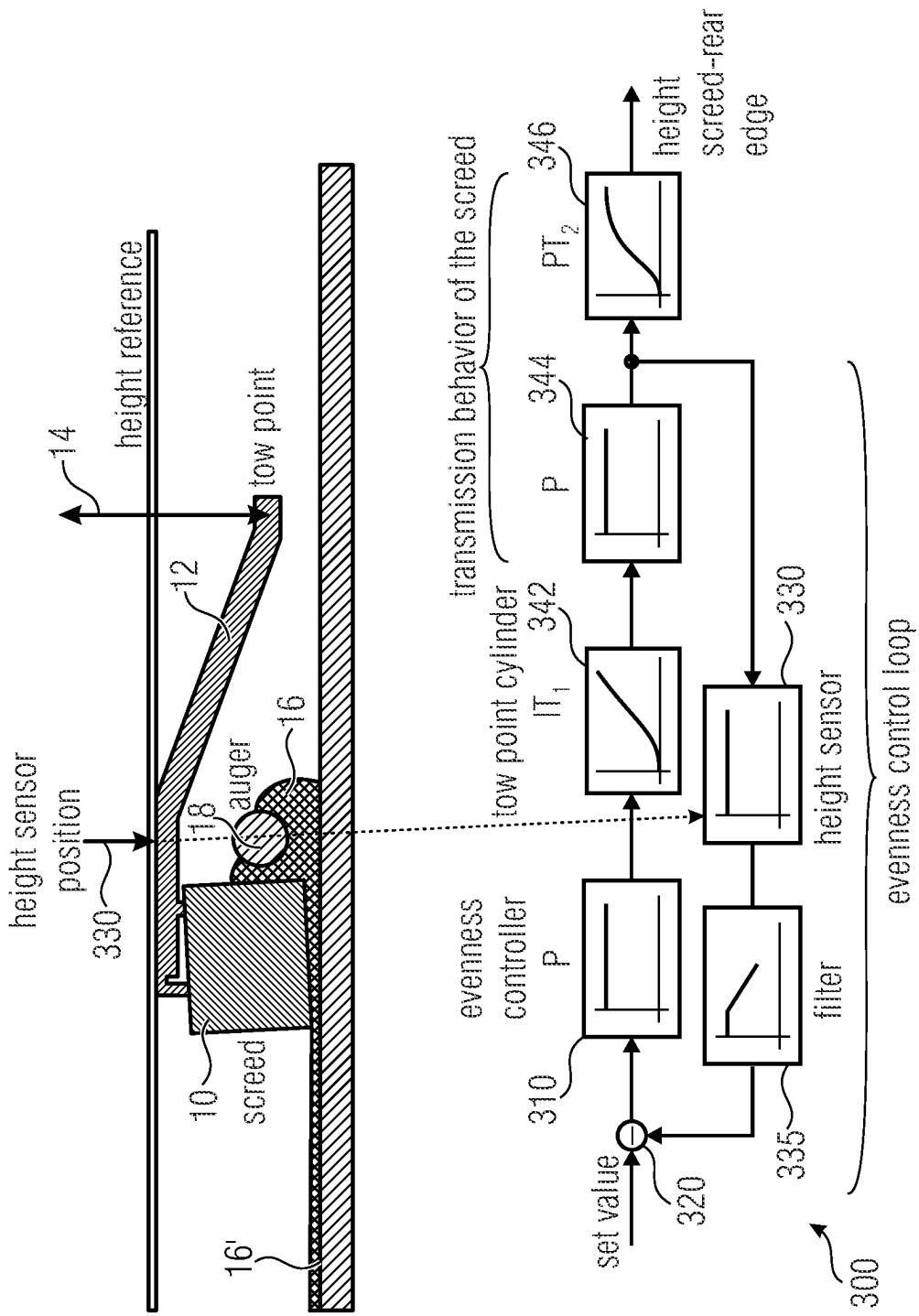
height sensor position
330
height reference
14
tow point
12
16
auger
18
10
screed
16'
transmission behavior of the screed
tow point cylinder
IT1
342
P
344
PT2
346
height screed-rear edge
330
height sensor
filter
evenness controller
P
310
set value
320
335
evenness control loop
300

Fig. 3a

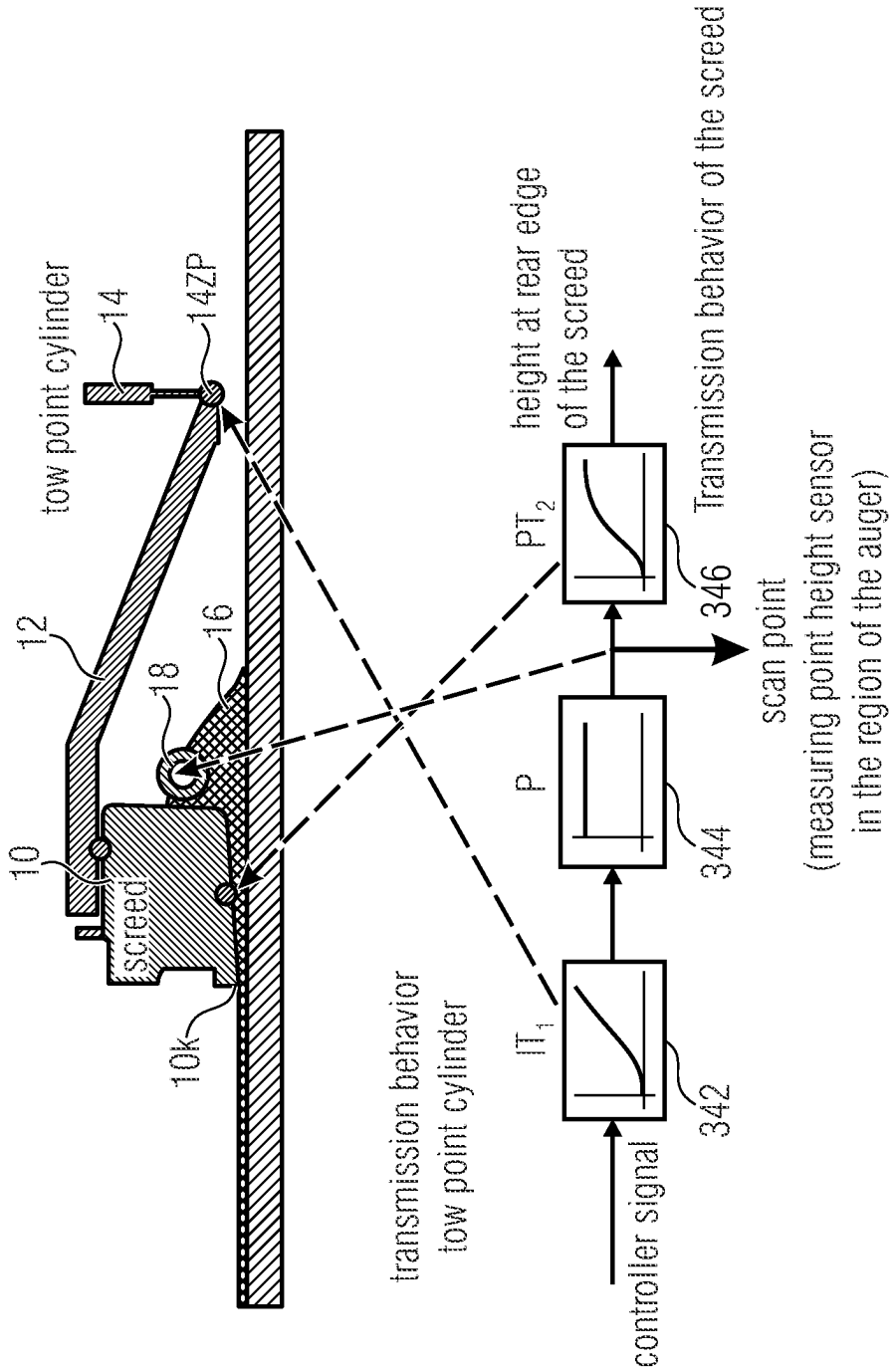
tow point cylinder
14
14ZP
12
16
18
10
screed
10k
transmission behavior
tow point cylinder
controller signal
$IT_1$
342
P
344
$PT_2$
height at rear edge
of the screed
346
Transmission behavior of the screed
scan point
(measuring point height sensor
in the region of the auger)

Fig. 3b

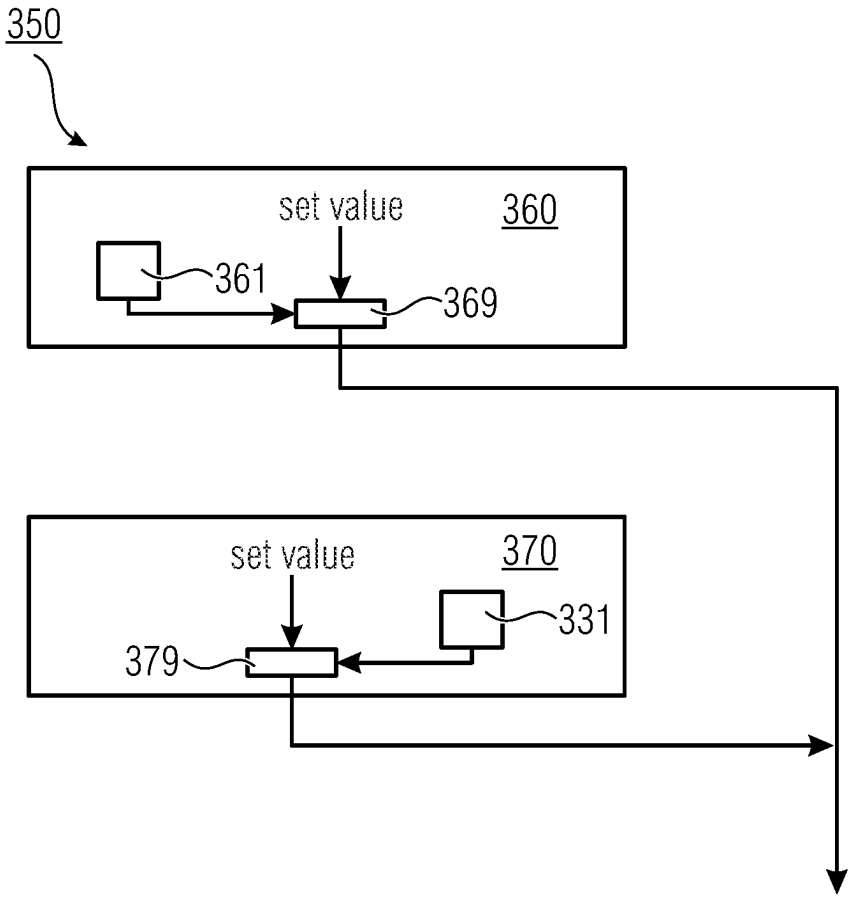


Fig. 3c

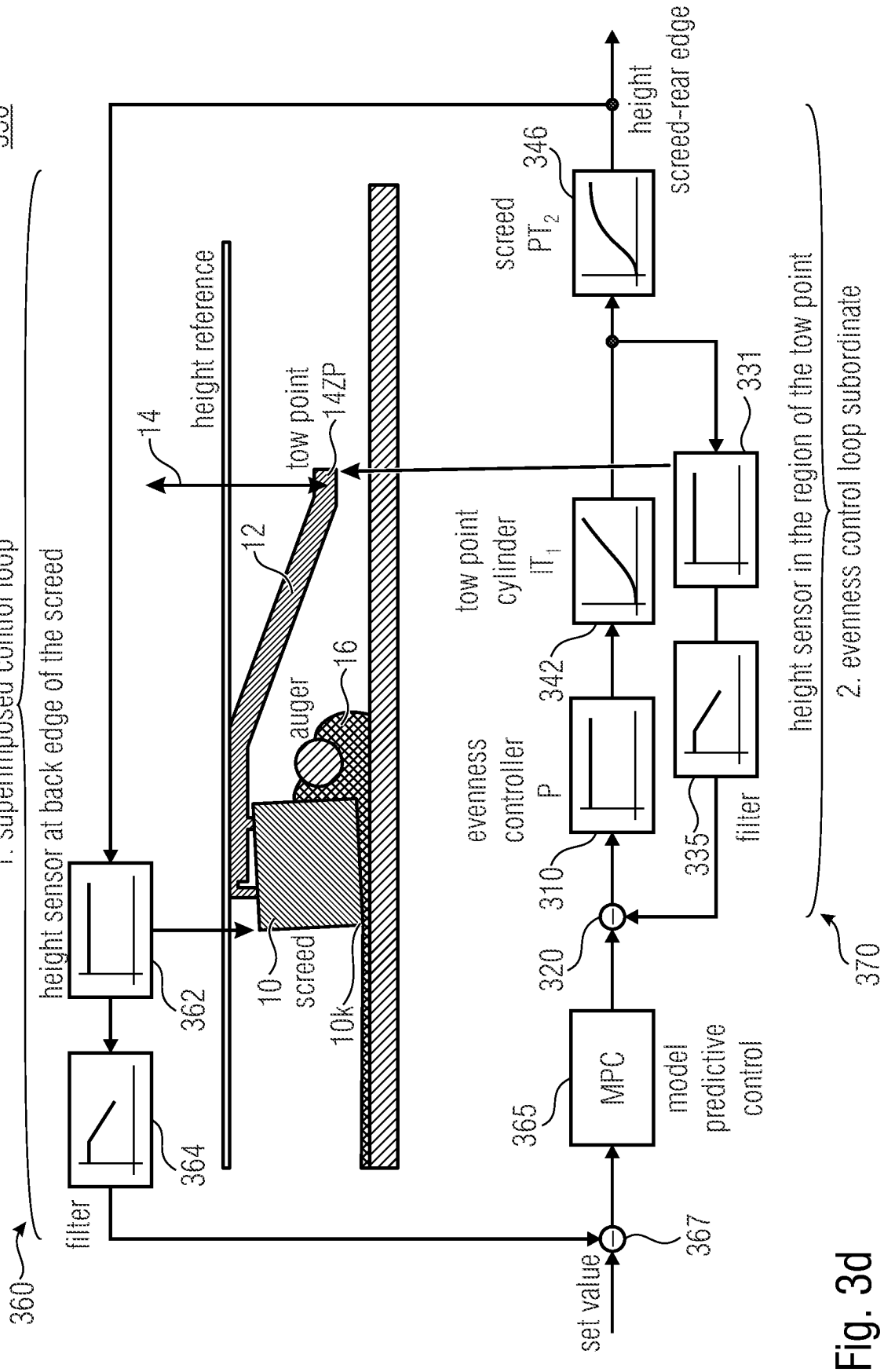
350
1. superimposed control loop
height sensor at back edge of the screed
362
filter
364
360
height reference
14
tow point
14ZP
12
auger
16
10
screed
10k
set value
367
365
MPC
model predictive control
320
evenness controller
P
310
tow point cylinder
IT1
342
screed
PT2
346
height
screed-rear edge
331
filter
335
height sensor in the region of the tow point
2. evenness control loop subordinate
370

Fig. 3d

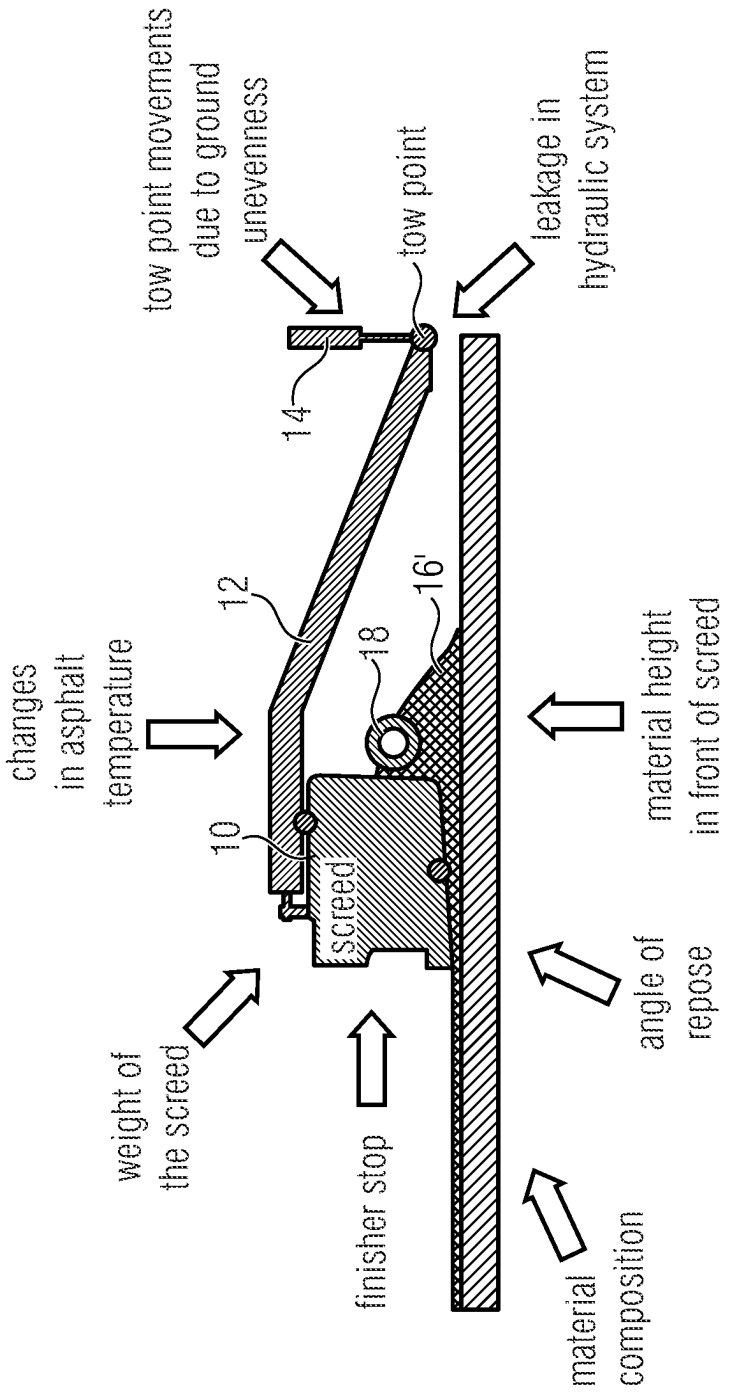
tow point movements due to ground unevenness
tow point
leakage in hydraulic system
14
12
16'
18
changes in asphalt temperature
10
screed
material height in front of screed
weight of the screed
finisher stop
angle of repose
material composition

Fig. 3e

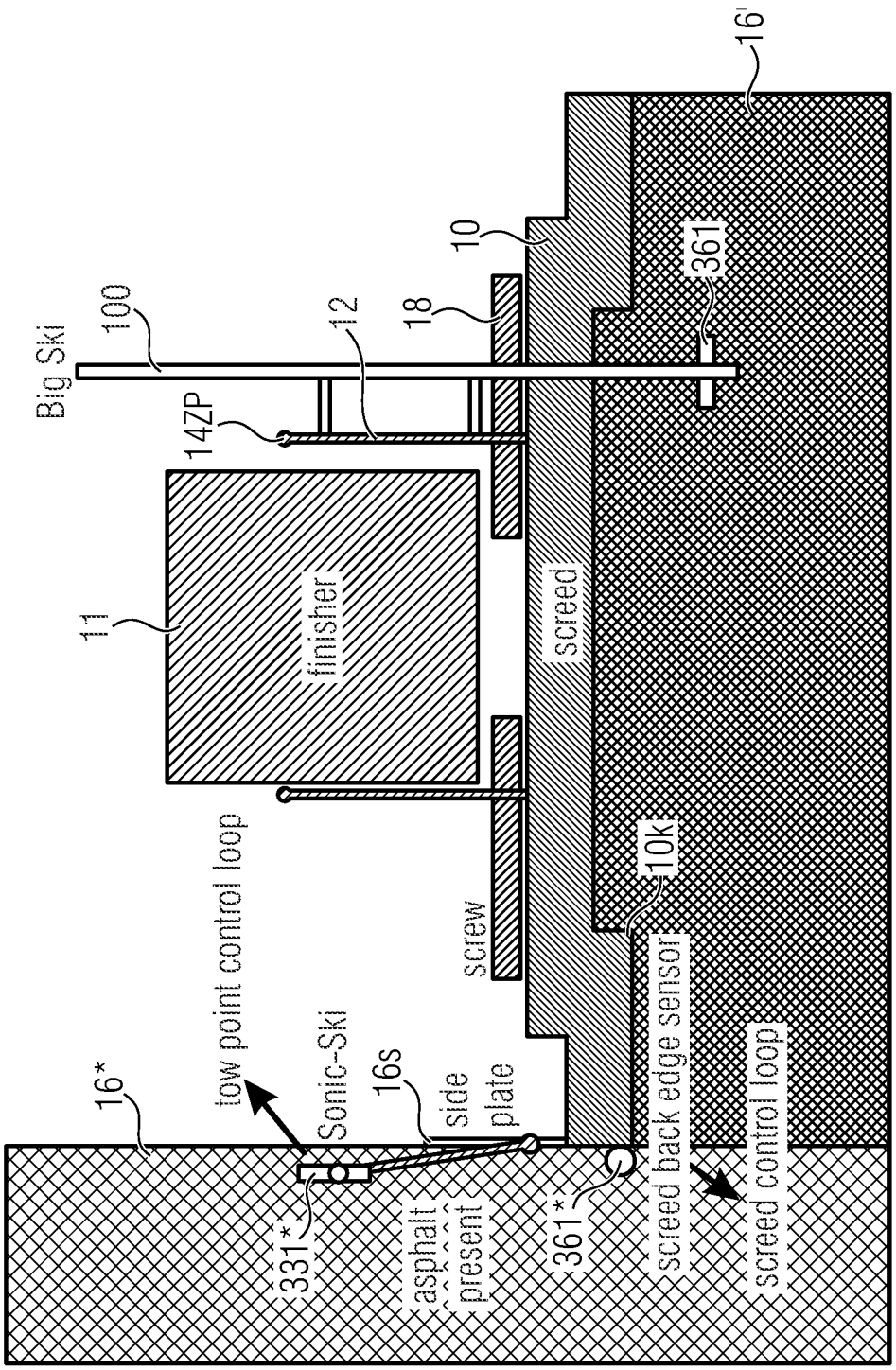
16'
10
361
Big Ski
100
12
18
14ZP
11
finisher
screed
tow point control loop
10k
screw
Sonic-Ski
16s
side plate
16*
331**
asphalt present
361**
screed back edge sensor
screed control loop

Fig. 3f

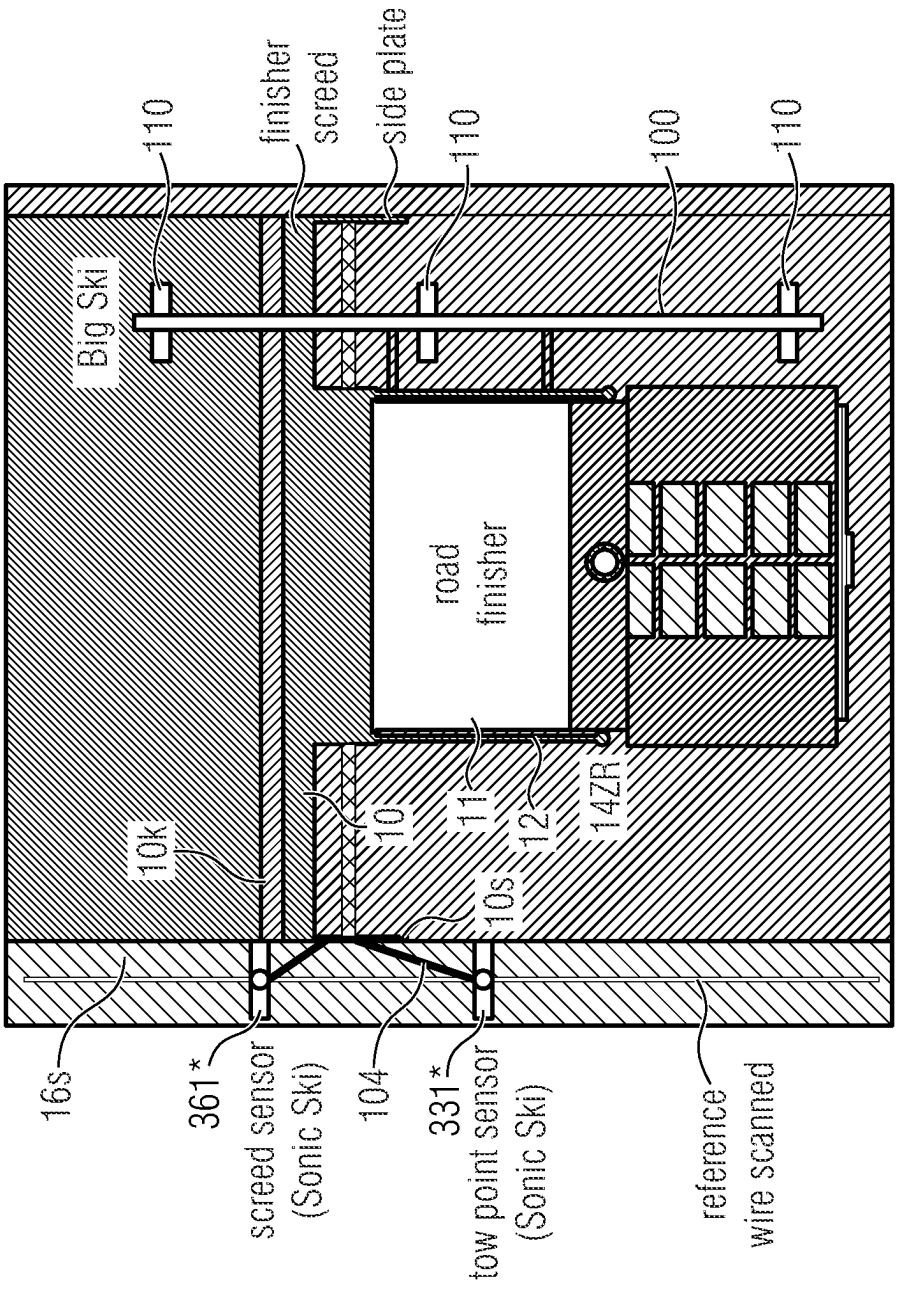
110
finisher screed
side plate
110
100
110
Big Ski
road finisher
10k
10
11
12
14ZR
10s
16s
361*
screed sensor (Sonic Ski)
104
331*
tow point sensor (Sonic Ski)
reference wire scanned

Fig. 3g

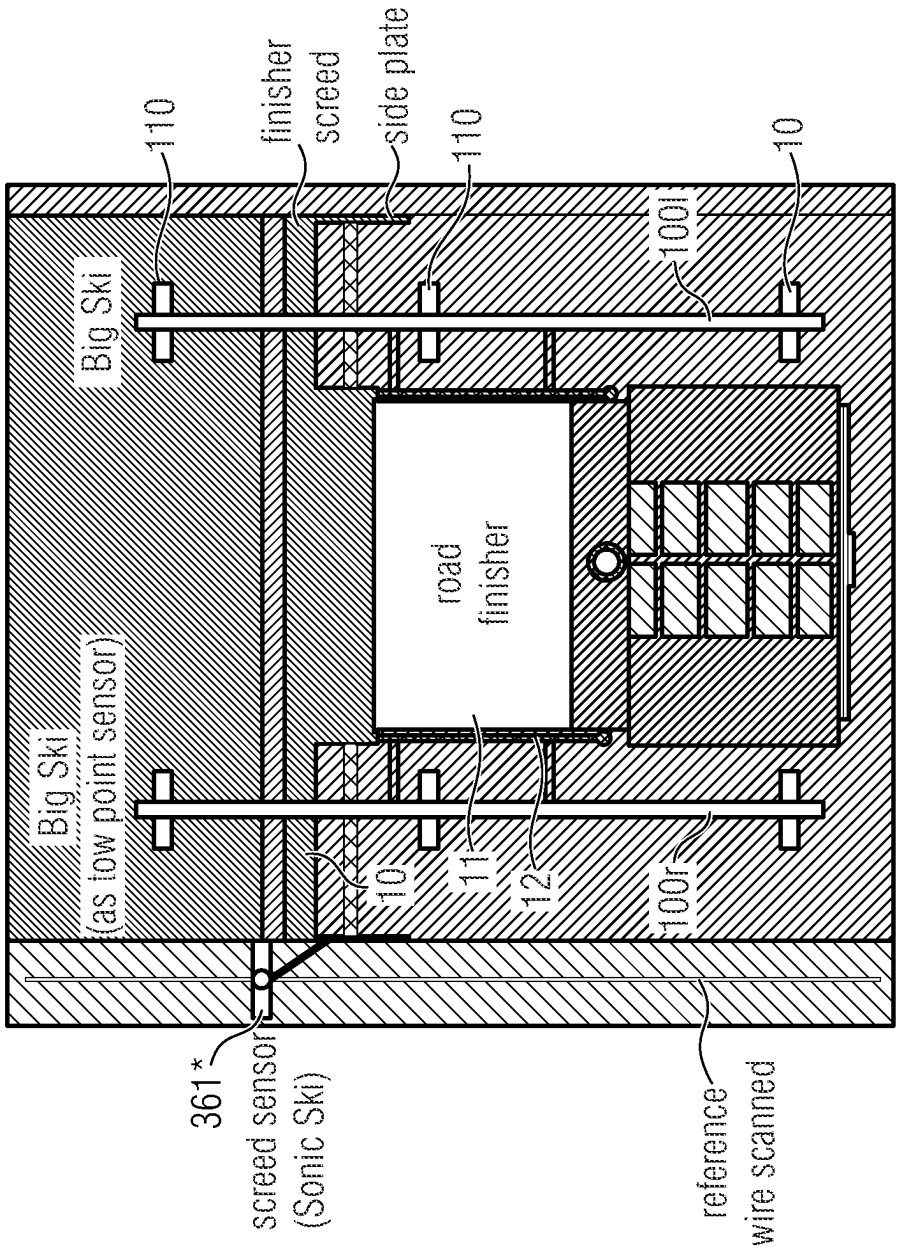
110
finisher screed
side plate
110
10
100l
Big Ski
Big Ski
(as low point sensor)
road finisher
10
11
12
100r
361*
screed sensor (Sonic Ski)
reference wire scanned

Fig. 3h

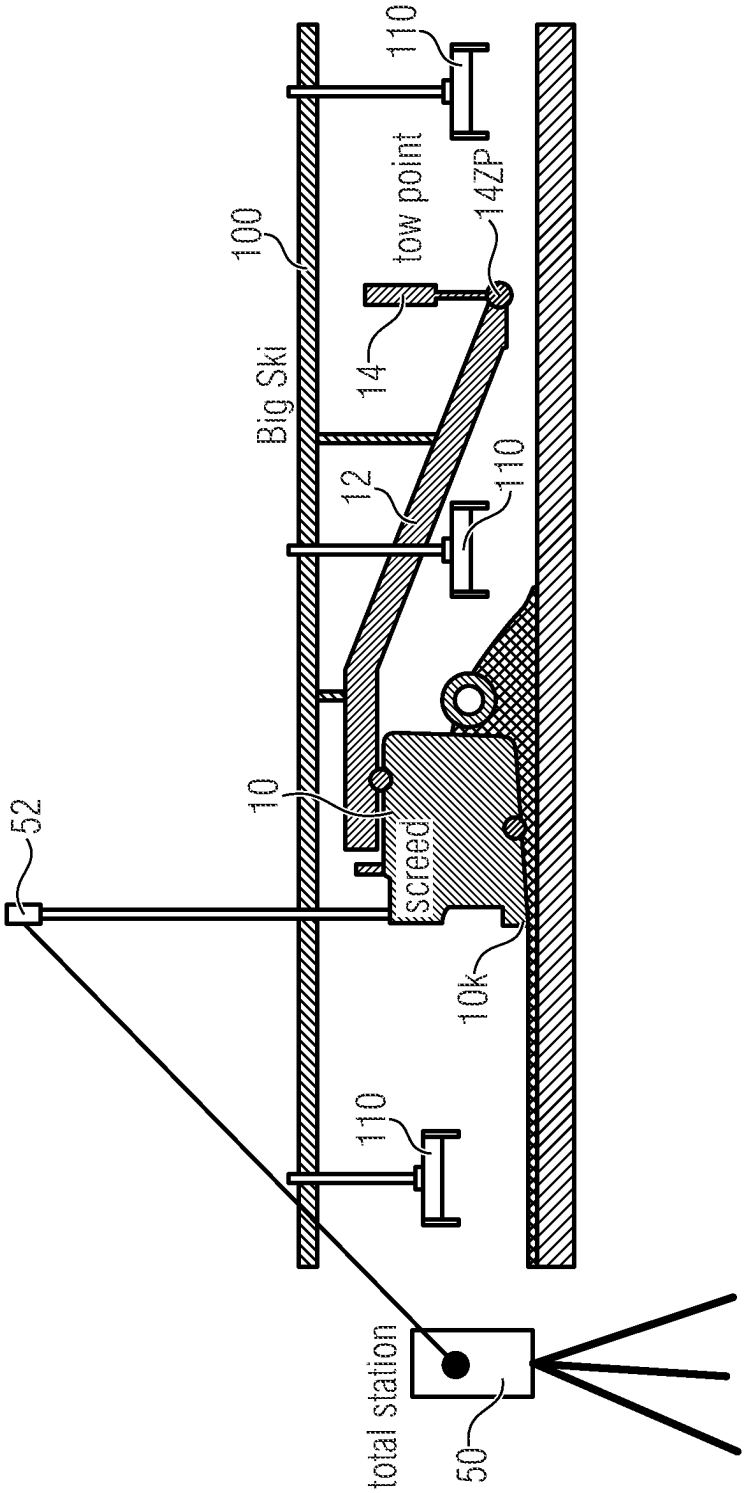
110
tow point
147P
100
Big Ski
14
12
110
52
10
screed
10k
110
total station
50

Fig. 3i

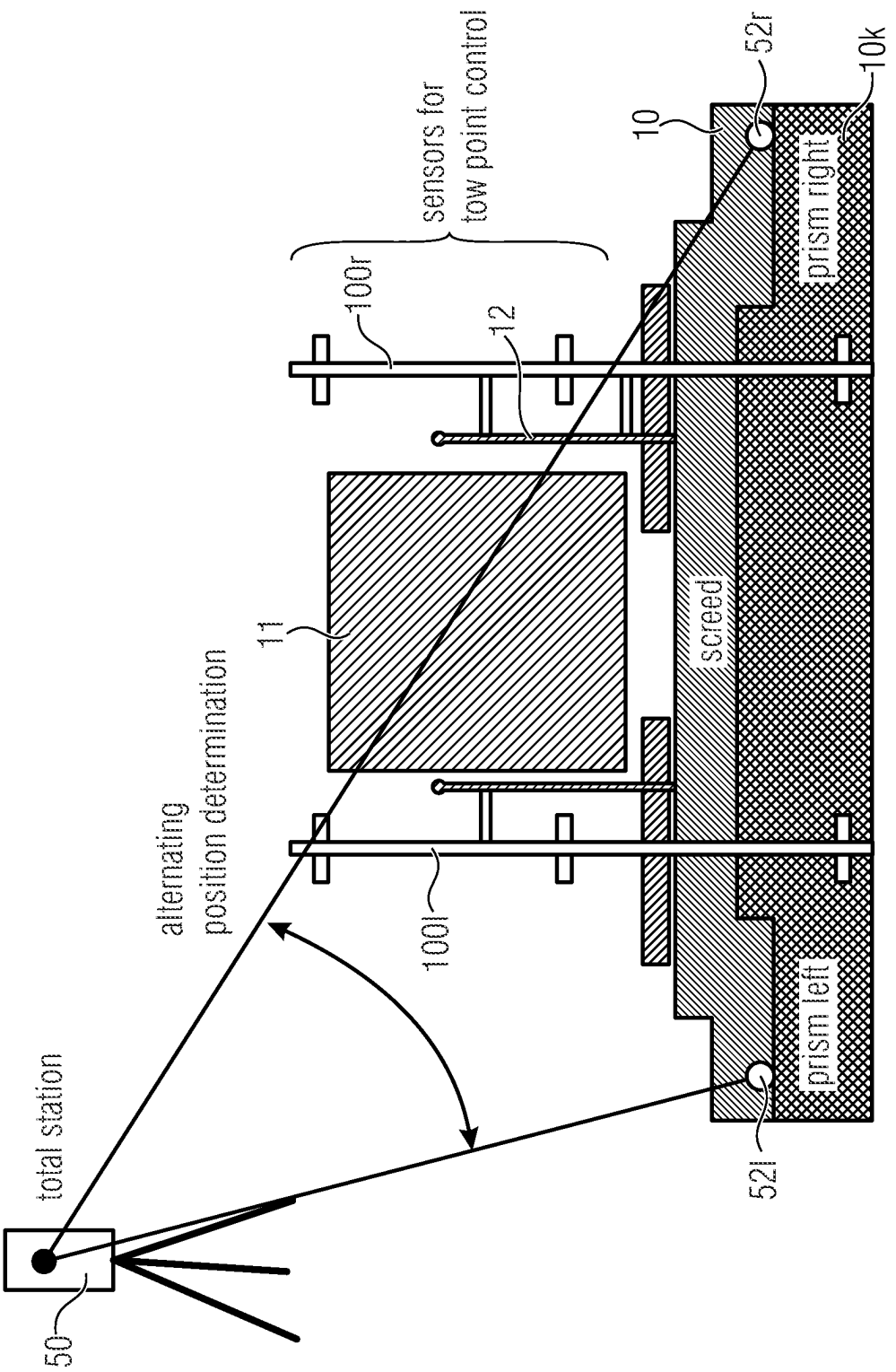
total station
50
alternating
position determination
11
12
sensors for
tow point control
100r
100l
10
52r
52l
10k
prism right
prism left
screed

Fig. 3j

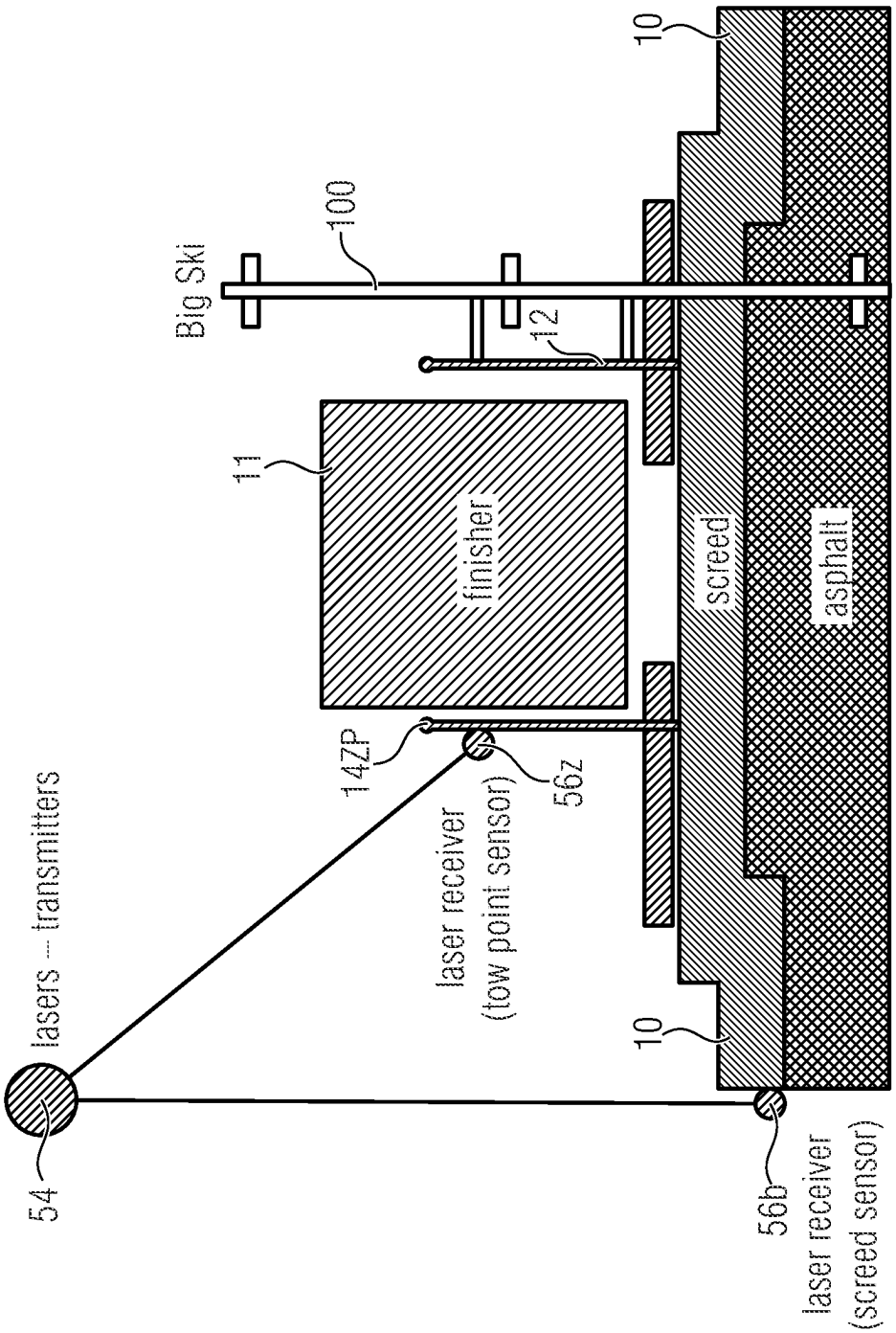
10
100
Big Ski
12
11
finisher
screed
asphalt
14ZP
56z
lasers — transmitters
laser receiver
(tow point sensor)
10
54
56b
laser receiver
(screed sensor)

Fig. 3k

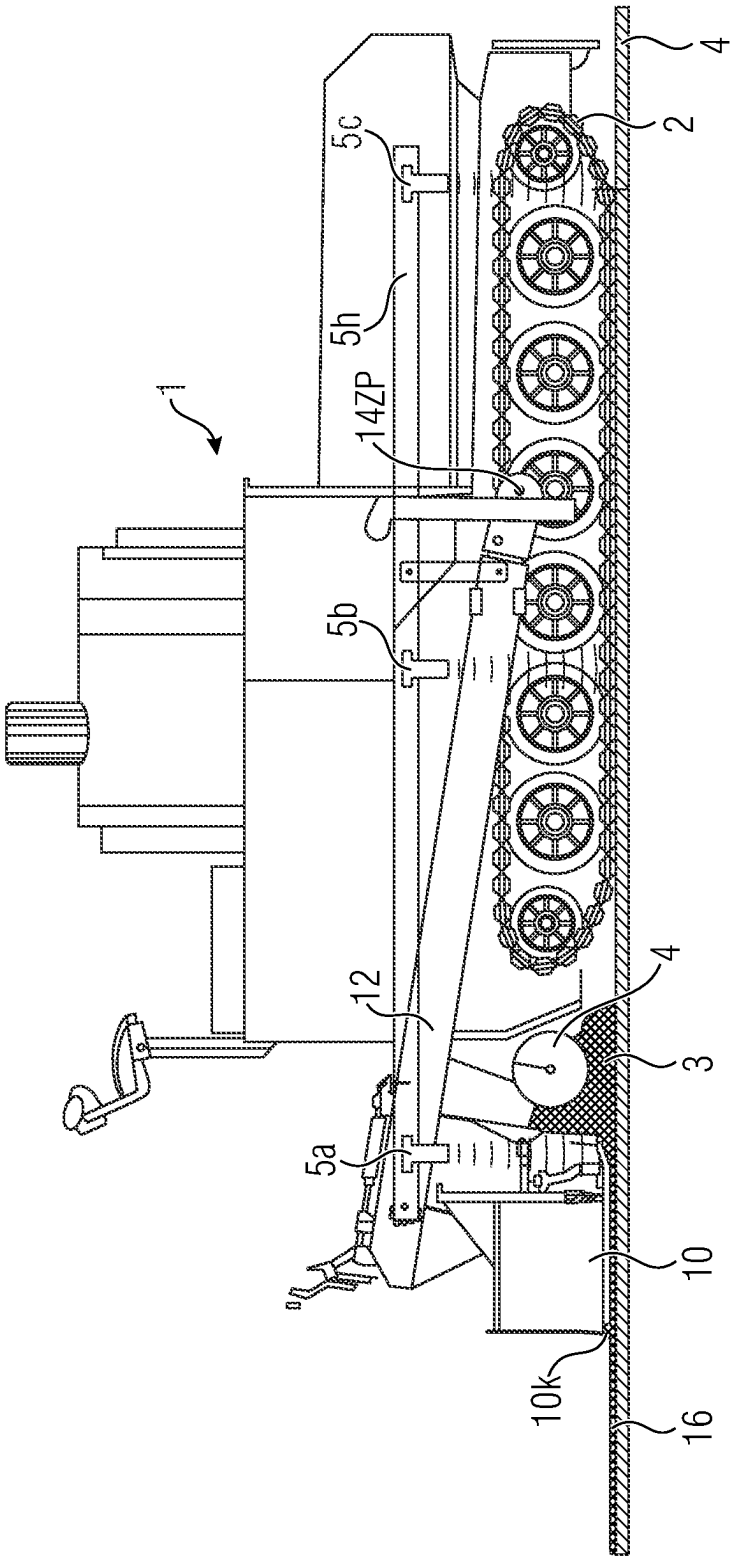


Fig. 4

# MEASURING SYSTEM AND CONTROLLER

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of copending International Application No. PCT/EP2020/052497, filed Jan. 31, 2020.

Embodiments (aspect 1) relate to a measuring system and to a construction machine comprising a measuring system. Embodiments of this first aspect relate to a measuring system and a construction machine comprising a measuring system. Embodiments of this first aspect relate to a measuring system including a carrier with attached or integrated sensor heads.

Another embodiment (aspect 2) relates to a measuring system, a corresponding method, and a construction machine. Embodiments of this second aspect relate to a measuring system comprising a calculation unit that determines a regression line.

Another embodiment (aspect 3) relates to a controller for a construction machine, a screed control system and a corresponding method. Embodiments of this third aspect are a controller having two control loops, and in particular for controlling the screed of a road finishing machine.

## BACKGROUND OF THE INVENTION

FIG. **4** shows a known road finishing machine as described, for example, in EP 0 542 297 A1. The road finishing machine in its entirety is designated by the reference numeral **1** and comprises a crawler track **2** with which the road finishing machine **1** travels on the prepared ground **4**. A height-adjustable screed **10** is arranged at the rear end of the road finishing machine **1** in the direction of travel, which is steered at the road finishing machine **1** by means of a tow arm **12** at a tow point **14** ZP. The height of the tow point **14** ZP can be adjusted by means of the cylinder **14** (not shown). A supply **3** of the asphalt material is located in front of the screed **10**, and this supply is kept substantially constant over the entire width range of the screed **10** by appropriate control, known per se, of the rotational speed of a spiral-type conveying device **4**. The screed **10** floats on the asphalt of the road surface **16** to be produced. The thickness of the road surface to be finished before its final consolidation by road rollers is adjusted by controlling the height position of the rear edge **10***k* of the screed **10**. This height control is induced by changing the tilt angle of the screed **10**, and is typically accomplished by controlling actuating cylinders that engage the front ends of the tow arms **12**. The road finishing machine includes three ultrasonic sensors **5***a*, **5***b*, **5***c* attached to a holder **5***h*. The holder **5***h* is attached to the tow arm **12**. The three ultrasonic sensors **5***a*, **5***b*, **5***c* are used to scan a reference surface, which may be formed, for example, by an already paved or old track of the road surface.

### Aspect 1

In construction machines, such as road construction machines in particular, the distance to the ground or to a reference, such as a tensioned rope or a curb or an already paved adjacent layer, is measured at one or more points, as explained in connection with FIG. **4**. For this purpose, ultrasonic sensors have become established on the market in recent years, which are mounted by means of cantilevers, e.g. to a screed of the road finishing machine, a tow arm of a road finishing machine and/or a chassis of the road finishing machine. In some applications, a so-called Sonic-Ski is used, which combines several parallel measuring heads to form one distance sensor.



In another conventional solution (Big Sonic-Ski or in short Big Ski), a plurality of distance sensors, such as ultrasonic measuring heads or also sensors based on another measuring principle, such as lasers, are attached to the tow arm via a common linkage. The linkage extends in the direction of travel approximately along or even beyond the length of the machine and is arranged such that a distance to the ground can be measured at two, three or more measuring points along this linkage or direction of travel. For example, one sensor may be aligned with the applied layer, while another sensor is aligned with the ground for the layer to be applied. Thus, two or more sensor heads are provided here, with one sensor head located in front of the screed and one sensor head located behind the screed.

This so-called Big Sonic-Ski (or Big Ski) application has a number of advantages, such as the fact that systematic faulty measurements, e.g. caused by stones on the ground, can be faded out or averaged out. A disadvantage of this so-called Big Sonic-Ski is that the installation effort for the linkage and the individual sensor heads is quite high. Based on the fact that, in order to prevent possible theft, such measuring systems are taken off overnight, this installation effort is not negligible in the daily work routine. Therefore, there is need for an improved approach.

## SUMMARY

An embodiment may have a construction machine including a measuring system, wherein the measuring system includes a carrier connectable to the construction machine, such that the carrier extends along a longitudinal axis of the construction machine, especially laterally to the same, including: at least a first portion of the carrier; wherein the first portion includes a plurality of sensor heads attached to or integrated with the first portion for non-contact measurement against a ground or reference as well as first and second end faces, and wherein the first portion includes a second connecting element at a second end face, the second connecting element being connectable to a first connecting element such that both a mechanical and electrical connection is formed.

Another embodiment may have a construction machine, in particular a road construction machine such as a road finishing machine of road milling machine including a screed and a screed control system including a control and at least one actuator for tow point adjustment, wherein the control is connected to a first sensor in the area of the screed and to a second sensor in the area of the tow point, and wherein the controller is configured to adjust a tow point of the screed, wherein the controller includes a first and a second control loop, wherein the first control loop varies the tow point in dependence on a first sensor value and wherein the second control loop varies the tow point in dependence on a second sensor value, wherein the first sensor value, measured with the first sensor, represents a distance to a ground or a reference in the area of the screed, and wherein the second sensor value, measured with the second sensor, represents a distance to a ground or reference in the area of the tow point, wherein the reference in the area of the screed and the reference in the area of the tow point includes an already deposited layer or a ground for the layer to be deposited or a rope along the ground or an edge along the ground or a curb or a line running along the ground or a

reference relative to a central transmitter or relative to a total station or relative to a projected laser plane, or wherein the reference in the area of the tow point includes an already deposited layer or a ground for the layer to be deposited or a rope along the ground or an edge along the ground or a curb or a line running along the ground or a reference relative to a central transmitter or relative to a total station or relative to a projected laser plane.

According to another embodiment, a method for controlling a road construction machine including a screed may have the steps of: adjusting a tow point of the screed by using a first and second control loop, varying the tow point in the first control loop in dependence on a first sensor value; and varying the tow point in the second control loop in dependence on a second sensor value, wherein the first sensor value represents a distance to a ground or a reference in the area of the screed, and wherein the second sensor value represents a distance to a ground or a reference in the area of the tow point, wherein the reference in the area of the screed and the reference in the area of the tow point includes an already deposited layer or a ground for the layer to be deposited or a rope along the ground or an edge along the ground or a curb or a line running along the ground or a reference relative to a central transmitter or relative to a total station or relative to a projected laser plane, or wherein the reference in the area of the tow point includes an already deposited layer or a ground for the layer to be deposited or a rope along the ground or an edge along the ground or a curb or a line running along the ground or a reference relative to a central transmitter or relative to a total station or relative to a projected laser plane.

Another embodiment may have a non-transitory digital storage medium having a computer program stored thereon to perform the inventive method when the program runs on an inventive construction machine including a measuring system, wherein the measuring system includes a carrier connectable to the construction machine.

An embodiment provides a measuring system or arrangement for a construction machine, such as a road finishing machine or milling machine. The measuring system comprises a carrier connectable to the construction machine (or a component, such as the screed (or plank) or the tow arm of the construction machine), for example, such that the carrier extends along a ground. For example, the carrier may extend along a longitudinal axis of the construction machine, laterally thereto. The carrier comprises at least a first portion, the first portion having a plurality of sensor heads attached to or integrated with the first portion for non-contact measurement against a ground or, in general, reference. These are aligned, for example, in parallel, i.e. have a scanning area extending in parallel or substantially parallel. The first portion has a second connecting element at a second end face, the second connecting element being connectable to a first connecting element such that both a mechanical and electrical connection is formed.

According to the embodiments, an electrical connection is understood to be a direct contact, an inductive connection or a contactless connection.

According to further embodiments, the measuring system comprises a second portion of the carrier, wherein the second portion also comprises a plurality of attached/integrated (parallel) sensor heads. The second portion has the first connecting element at a first end face such that the second connecting element of the first portion is connectable to the first connecting element of the second portion. According to embodiments, a second portion may have a second connecting element at a second end face and/or the first portion can have a first connecting element at a first end face. In this respect, these two portions can be formed identically so that not only two portions can be plugged together to form a carrier, but also a plurality of portions.

Embodiments of the present invention are based on the finding that the use of fastened/integrated sensor heads in a carrier which is subdivided into one or more portions can significantly reduce the assembly effort. Due to the fact that the connecting elements form a mechanical and an electrical connection at the same time, no wiring is needed. According to embodiments, the connection between the portion and the construction machine can also be made via a corresponding connecting element. For example, the first portion can be connectable to the construction machine (which has a corresponding second portion as a counterpart) by means of its first connecting element. Here, too, an electrical connection can be formed in addition to the mechanical connection, for example. According to embodiments, the measuring system can be extended by the further portions with attached/integrated sensor heads in order to be able to scan a large area simultaneously. Thus, when a measuring system with two portions per carrier is set up in this way, only two connections (one to the machine and one between the two portions) need to be made, rather than attaching and wiring the individual sensor heads. This saves a significant amount of time over the conventional approach. The fact that the sensor heads are also all aligned with one another also means that no further adjustment is needed, which ensures overall measurement quality.

There are different approaches for the mechanical connection. Three embodiment variations are explained below, although others would also be possible.

According to a first embodiment variation, a type of hook connection can be used. According to embodiments, the first and/or the second connecting element may have a hook such that the first connecting element and the second connecting element may be engaged by a rotational movement. According to further embodiments, the hook of the first connecting element or the hook of the second connecting element or the hooks of the first connecting element and the second connecting element may have an engagement surface, which is opened substantially perpendicular to the longitudinal direction of the respective portion.

Here, the rotational movement is defined by an end stop, which needs the first and second end face, or end surfaces to be in contact. According to further embodiments, the first and/or the second connecting element may comprise an electrical coupler extending substantially along the longitudinal direction of the respective portion.

According to the further embodiments, a shear movement of the two portions or of a portion relative to another connecting element can also form the connection. In this embodiment, the first and/or the second connecting element may comprise a profile extending substantially perpendicular to the longitudinal direction of the respective portion and having an end stop such that the two connecting elements are connectable by a translational movement substantially perpendicular to the longitudinal direction of the respective portion. According to embodiments, the first connecting element comprises a lever mechanism, for example comprising an eccentric, for translationally fixing the first connecting element to the second connecting element. According to an embodiment, the first and/or the second connecting element may each comprise an electrical coupler extending substantially perpendicular to the longitudinal direction of the respective portion.

According to another embodiment variation, a translational movement of the two portions relative to each other for forming the connection would also be conceivable. Therefore, according to comparative examples, the first connecting element may comprise a sleeve extending substantially in the longitudinal direction of the respective portion, and wherein the two connecting elements are connectable by inserting the second connecting element into the sleeve. According to embodiments, the first and/or the second connecting element may comprise a respective electrical coupler extending substantially along the longitudinal direction of the respective portion.

According to further embodiments, the measuring system has a fastening element. This can be connected to the construction machine or a component of the construction machine and has a first and/or a second connecting element. This can be done, for example, in such a way that the first portion can be connected to the construction machine or the component of the construction machine.

According to embodiments, the first and/or the second portion may have sensor heads aligned on a longitudinal side perpendicularly to the longitudinal axis of the first and the second portion. In other words, the sensor heads are aligned with the ground (in the installed state), i.e. the sensor heads are aligned with the already applied layer or with the ground for the layer to be applied.

As already explained above, the sensor heads are attached or integrated, with a plurality, i.e. at least three sensor heads, being attached/integrated per portion. The higher the number or density of the sensors, the better unevenness of a certain wavelength, e.g. 5 m, is compensated.

According to embodiments, the measuring principles of the sensor heads may differ, i.e., the sensor heads may be designed, for example, as ultrasonic sensors, as laser sensors or as radar sensors or the like. According to a variant, the sensor heads are spaced apart from each other, e.g. 10 cm, 20 cm, 33 cm, 40 cm or generally in the range of 5 cm to 50 cm or 2 cm to 100 cm. The distance can be adjusted accordingly depending on the measuring principle of the sensor heads. For example, the distance can be selected so that there is an equal distribution over the respective section or over the carrier. Furthermore, the distance from sensor/sensor head to sensor/sensor head can change, such as increase. This is advantageous when compensating for unevenness in the layer to be applied with certain frequencies/wavelengths.

According to further embodiments, the measuring system may comprise, for each first and/or second portion or carrier, at least one first further sensor head which is aligned parallel to the longitudinal axis and/or which is arranged at the first and/or second end face; and/or wherein the first further sensor head is configured to perform a reference measurement. Here, according to embodiments, the measuring system may comprise, for each first and/or second portion, a second sensor head arranged along the longitudinal axis of the respective first and/or second portion or of the carrier and located at the opposite end face to the first further sensor head. For determining the reference, according to further embodiments, the measuring system may comprise a reflector (e.g. parallel to the longitudinal axis) or an inclined reflector (e.g. 135° inclined to the longitudinal axis) at the first and/or second end face. The reflector may also be integrated/formed in the receptacle of one and/or more sensor heads.

According to further embodiments, it would also be conceivable for the measuring system to comprise, per first and/or second portion or per carrier, at least one additional sensor head, which is aligned parallel to the longitudinal axis and/or which is arranged at the first and/or second end face; the additional sensor head is configured to determine a distance to an object performing a relative movement with respect to the construction machine or a component of the construction machine.

According to embodiments, measurements of the sensor heads are performed substantially simultaneously, i.e. within a time window of 3 s, 1 s, 0.5 s, 0.1 s or smaller, for example. Distance measurements to the ground (reference to the already applied layer or to the ground for the layer to be applied) and/or to the object, and/or as reference measurement(s) are performed substantially simultaneously (synchronous measurement within a time window, as indicated above). That is, it is possible for all the sensor heads arranged in the measuring system to perform measurements substantially simultaneously. This is advantageous with regard to the measurement accuracy of the measuring system, since a simultaneous measurement in principle provides a snapshot of, for example, the ground or reference profile and the reference measurement(s) under the same conditions (for example, environmental conditions). In contrast to an asynchronous measurement (not performed at the same time, for example one after the other), changes in distances or external conditions, for example triggered by mechanical vibrations (oscillations) of the machine or the tool or of machine parts or triggered by temperature fluctuations, are not relevant in a measurement performed essentially at the same time, since at the moment of the (simultaneous) measurements, for example, the ground or reference profile is detected by the measuring system at the correct distance and reference measurement(s) are also performed under the same conditions. Thus, a correct reference profile or correct profile of the ground is detected by all the sensor heads in all the portions and all the carriers of the measuring system. Furthermore, simultaneous measurement is advantageous with regard to a high measuring rate (scan rate), as is needed nowadays for leveling in road construction (for example, height leveling of the screed).

According to a further embodiment, the first and/or the second portion comprise a display, such as an LED, LED display. The display or LED display is configured to display a connection status between the first and second or each further portion or to display information, e.g. regarding a deviation, of the measuring system or of a regulating and/or control system connected to the measuring system. An LCD display or the like is also conceivable here as a display on which, for example, text and/or symbols are displayed.

According to further embodiments, the measuring system may include a GNSS sensor, an inclination sensor, an infrared sensor, a temperature sensor, a position sensor (Inertial Measurement Unit), or another sensor. According to examples, each portion may also include illumination.

According to a further embodiment, the measuring system has a first connecting element on a (first) end face, the first connecting element being connected to a second connecting element which is attached to the machine, example, and on the second end face where a further measuring system, e.g. a distance measuring system, is attached.

According to further embodiments, a calculation unit is configured to use the first measuring value and the second measuring value to determine a regression line together with a slope of the regression line relative to the ground or the reference and, based on the slope, to determine an angle which describes the slope of the regression line and the position of the component of the construction machine relative to the ground or the reference.

Another embodiment relates to a construction machine, such as a road construction machine comprising a measuring system explained above.

Aspect 2

Components of construction machines, such as a screed, are monitored with regard to their position. For example, there are angle or inclination sensors, which determine the rotation of the screed about its longitudinal axis, i.e. the tilting of the screed relative to the ground. Since the screed or components of construction machines in general are subject to considerable disturbance influence, such as vibrations, mechanisms are needed to compensate for this disturbance influence.

In the state of the art, for example, the inclination is determined using different measuring principles in order to combine the advantages of different measuring principles in terms of "immunity to disturbance", accuracy, etc.

Embodiments of the present invention provide a measuring system for a construction machine, wherein the measuring system has a carrier connectable to a component of the construction machine. In the basic implementation, the measuring system includes at least a first, second, and third sensor heads and a calculation unit. The first, second and third sensor heads are connected to the carrier. The alignment may again be parallel; the system may also be used according to embodiments according to aspect 1. In general, the sensor heads are configured to measure a first distance from the first sensor head to the ground or a reference to obtain a first measuring value, or to measure a second distance from the second sensor head to a ground or a reference to obtain a second measuring value, or to measure a third distance from the third sensor head to a ground or a reference to obtain a third measuring value. The calculation unit is configured to determine, based on the first, second and third measuring values, a regression line together with a slope of the regression line relative to the ground or the reference and, based on the slope, to determine an angle which describes the slope of the regression line and thus the position of the component of the construction machine relative to the ground or the reference.

According to embodiments, the component may comprise a tow arm or a screed or a screed connected fixedly via the tow arm, rigidly and/or at least rigidly during the working process, i.e. in particular with a fixedly defined relationship or a relationship at least defined fixedly during the working process.

Embodiments of the present invention are based on the finding that a regression line and, in particular, the position of the regression line in space can be determined by three measuring values. Assuming that the sensors (which are spaced apart from each other, for example) are arranged on a carrier which is arranged or fixed in a known or fixed position with respect to the component, a regression line which lies at a fixed angle with respect to the component can be determined by the three measuring values. For example, the regression line can be arranged parallel to the position of the component.

Starting from an initial state in which the position of the component is known, a conclusion can be drawn on a change in position of the component by observing the change in position of the regression line. Knowing the position of the regression line or the position of the sensor heads relative to the component (e.g. distance along the carrier and offset), it is also possible to determine the position (relative to the reference or the ground) of the regression line and thus also of the component. Since the regression line usually does not depend too much on individual measurements, a very accurate and at the same time robust measurement is made possible.

The use of more than two sensor values or, in particular, the use of more than two measuring points in a sequence of temporally successive measurements makes the results of the regression line (calculation) particularly stable and robust. Furthermore, the values change uniformly over the carrier due to the rigid coupling so that the position is advantageously detectable even despite disturbances (objects on the ground or vibrations). By determining the position of the regression line, the position, such as an inclination of a component, can be detected in a robust manner.

According to the embodiment, the carrier can be arranged behind the screed, e.g. firmly connected to the screed. The carrier is then directed towards the layer just applied and, using the layer as a reference, enables the position of the screed to be determined. For example, it would be conceivable for the carrier to extend along the longitudinal axis in order to determine the rotation of the screed about its longitudinal axis (note: the longitudinal axis of the screed extends transversely to the direction of travel of a road finishing machine as described at the beginning). If the carrier is arranged transverse to the longitudinal direction or at an angle (e.g. 45°), a profile and/or additionally a lateral inclination (in addition to the profile) can be determined.

According to another embodiment, the measuring system around a further carrier with further (three) sensors can also be considered. It can be arranged behind the screed, for example. With this approach, two regression lines are then determined, with a lateral offset of the first regression line relative to the second regression line corresponding to a layer thickness. This layer thickness measuring system is robust to rotations of the screed because, assuming, for example, that the two carriers are in line or parallel to each other, the regression lines are also parallel. The parallel offset corresponds to the layer thickness, regardless of how the regression lines are in the solid angle.

In this respect, another embodiment provides a layer thickness measuring system. The layer thickness measuring system for a construction machine includes a carrier and further carriers connectable to a screed of the construction machine such that the carrier extends in front of the screed and the further carrier extends behind the screed. It further includes a first, second, and third sensor heads connected to the carrier and configured to measure a first distance from the first sensor head to a ground or reference to obtain a first measuring value, and to measure a second distance from the second sensor head to a ground or reference to obtain a second measuring value; and to measure a third distance from the third sensor head to a ground or reference to obtain a third measuring value. Additionally, further first, second and third sensor heads are provided, which are connected to a further carrier and are configured to measure a further first, second and third distance from the further first, second and third sensor head to the ground/reference to obtain a further first, second and third measuring value; a calculation unit is configured to determine a regression line based on the first, second and third measuring values and to determine a further regression line based on the further first, further second and further third measuring values. The calculation unit is configured to determine a layer thickness based on the position of the regression line relative to the further regression line.

According to embodiments, the layer thickness measuring system can be configured such that the mutual position of the carrier and the further carrier is known and thus the regression line and the further regression line can also be aligned so that they run parallel. As already mentioned, the offset of the regression lines to each other represents or corresponds to the layer thickness or, generally speaking, allows a conclusion to be drawn.

According to a further variation, the measuring system can also be attached to another component, such as the chassis itself, in order to determine a position here.

According to another embodiment, the measuring system may comprise four sensor heads arranged, for example, on a common carrier. According to embodiments, the calculation unit may be configured to define a regression line starting from a point cloud in order to determine the first, the second, the third and the fourth measuring values. The regression line is arranged in space such that the distances are, for example, minimal to the points of the point cloud.

Since a relative inclination to a reference or to the ground is determined by means of the regression line, the measuring system can be extended to include an inclination sensor, in which case the calculation unit is configured, for example, to determine an absolute inclination of the component of the construction machine on the basis of the absolute inclination, determined by the inclination sensor, together with the angle, determined via the regression line.

Starting from a driving condition (e.g. speed<2 km/h), several measuring values are determined in succession for each sensor head. To determine the regression line, time averaging is performed for each measuring point or time averaging of the regression parameters after repeated determination of these parameters. According to further embodiments, the averaging can also be carried out locally or in a different way.

The first and second sensor heads or, in embodiments of multiple sensor heads, the sensor heads are typically spaced apart. According to an embodiment, the calculation unit can be configured to take the distance of the sensor heads into account. This is especially important to determine the slope of the regression line. Furthermore, the calculation unit can be configured to use a velocity signal, which can be generated from a path signal or position signal, e.g. GNSS signal, to generate a path-related/position-related measurement from a time-related measurement. Thus, stationary disturbances can be reacted to.

Another embodiment provides a construction machine, such as in particular a road construction machine with a measuring system or a layer thickness measuring system.

Another embodiment provides a method for determining a position of a component of a construction machine using a measuring system having a carrier connectable to a component of the construction machine. The method comprises the following steps: determining, based on the first measuring value, the second measuring value, and the third measuring value, a regression line along with a slope of the regression line with respect to the ground; and determining, based on the slope, an angle describing the slope of the regression line and the position of the component of the construction machine with respect to the ground.

The method may, assuming further sensor heads on a further carrier, also comprise the following steps: determining a further regression line together with a slope of the further regression line relative to the ground based on the further first, second and third measuring values; determining an angle describing the slope of the further regression line and the position of the component of the construction machine relative to the ground based on the slope; and determining a layer thickness based on the regression line and the further regression line.

Another method refers to determining a layer thickness. This method comprises three steps: determining a regression line based on the first, second and third measuring values; and determining a further regression line based on a further first, second and third measuring values; determining a layer thickness based on the position of the regression line relative to the further regression line.

The method may also be computer-implemented according to embodiments. Therefore, another embodiment relates to a computer program for performing the method according to any of the previous aspects.

## Aspect 3

If the main task of a road finishing machine is considered, the same consist of ensuring continuous evenness during the paving process. However, due to a large number of different disturbances, there are such impacts that the desired evenness is at least impaired.

A decisive disadvantage of screed height levelling is that the measurement of the screed's height information does not take place near the rear edge of the screed, but in the region of the screed auger. This is ultimately a compromise solution so that, despite the very inert behavior of the screed, a needed dynamic reaction takes place at the tow point as soon as there is a control deviation in the height. The height leveling system adjusts the screed's tow point in such a way that the height deviation from the reference at the position of the height sensor (in the region of the screed auger) is compensated as quickly as possible. At this position, the height to the reference is thus maintained exactly. However, the decisive height at the rear edge of the screed can change over this point (height sensor in the region of the screed auger) so that ultimately a different height is set at the rear edge of the screed compared to the desired height reference value over time. Thus, the height of the screed's rear edge changes in relation to the reference, which in turn represents a deviation from the desired height and which is not compensated for by the leveling system.

A measuring system for a leveling system is shown, for example, in U.S. Pat. No. 5,356,238.

Practical experience also shows that with the leveling systems commonly used today, undesirable height deviations in the screed occur sometimes. Therefore, there is need for an improved approach.

Embodiments of the present invention provide a controller of a road machine having a screed configured to adjust a tow point of the screed. The controller includes a first control loop and a second control loop. The first control loop varies the tow point in dependence on a first sensor value, while the second control loop varies the tow point in response to a second sensor value. The first sensor value represents a distance (from the sensor) to a ground or reference in the region of the screed, while the second sensor value represents a distance (from the sensor) to the ground or reference in the region of the tow point.

According to embodiments, the first control loop considers a first set value during variation, while the second control loop considers a second set value during variation.

Embodiments of the present invention are based on the finding that splitting the controller into two control loops takes into account the situation where different disturbance variables act on the leveling. For example, the control loop which controls in the region of the tow point compensates

disturbance variables acting directly on the chassis. For example, this control loop can be implemented to be less inert than the other control loop in order to counteract the disturbance variable accordingly. The control loop, which determines its measuring values in the region of the screed essentially, compensates for the disturbance variables acting on the screed. These disturbance variables interact not only between the chassis and the tow point, as in the case in the second control loop, but also via the screed, including the "asphalt" mechanism, so that a more inert control loop can be used as a basis here. Dividing the two control loops increases the complexity of the controller, but allows disturbance variables to be controlled more individually and significantly better.

According to embodiments, the first control loop is configured to be more inert than the second control loop. For example, according to embodiments, each control loop may include a filter (first control loop first filter and/or second control loop second filter). According to embodiments, the first control loop is implemented for low-frequency control and has, for example, a low-pass filter with a low cutoff frequency. The second control loop can, for example, be implemented for high-frequency or higher-frequency control and comprise a low-pass filter with a higher cut-off frequency.

In the first control loop, a model is used to represent the transmission behavior of the screed according to embodiments. According to embodiments, this model can take into account a speed or distance traveled by the construction machine. According to further embodiments, the model may take into account a screed rotation about the longitudinal axis, a weight of the screed, and/or a tamper or vibration frequency of the screed. According to further embodiments, the model may account for a viscosity and/or a temperature of the layer or pavement to be applied. Furthermore, factors such as an angle of repose or a material height in front of the screed may also be taken into account. In this respect, the first control loop according to embodiments uses the model, which has as an input variable a speed, screed rotation around the longitudinal axis, viscosity and/or temperature.

According to further embodiments, the first control loop and the second control loop are configured to take into account a transmission behavior of the tow point adjustment and/or a transmission behavior of the screed. According to embodiments, the transmission behavior of the tow point adjustment can be described by an IT behavior (integral behavior with time component). The transmission behavior of the screed, for example, can be described approximately by a $PT_2$ behavior (proportional behavior with time component and a $2^{nd}$ order delay).

With regard to the sensors, it should be noted that, according to embodiments, these can be implemented as ultrasonic sensors or as laser sensors or as radar sensors or quite generally as distance sensors, which in the simplest case measure the distance to the ground or the applied layer. Of course, it would also be conceivable to measure relative to a reference (e.g. rope, edge or curb, line). It would also be conceivable to use a total station as a sensor system or laser receiver in combination with a central transmitter (3D control).

Another embodiment relates to a screed control system with a controller as explained above and an actuator for tow point adjustment.

According to embodiments, the screed control system has or is connected to a first sensor in the region of the screed and a second sensor in the region of the tow point.

Another embodiment relates to a construction machine, in particular a road construction machine with a corresponding controller or screed controller.

Another embodiment provides a method for controlling a road construction machine having a screed. The method comprises the steps of: adjusting a tow point of the screed using first and second control loops, varying the tow point in the first control loop in dependence on a first sensor value; and varying the tow point in the second control loop in dependence on a second sensor value. The first sensor value represents a distance to the ground or to a reference. The second sensor value represents a distance to the ground or to the reference.

According to further embodiments, the method may be computer-implemented.

Before embodiments of the present invention are explained below with reference to the accompanying drawings, it should be noted that all of the above aspects can be used in combination according to a variation. For example, the measuring system according to aspect 1 may serve as a sensor arrangement for the controller of aspect 3. Likewise, this measuring system of aspect 1 can serve as a sensor arrangement for the measurement methodology of aspect 2. Advantageously, the measurement methodology of aspect 2 can be connected to the controller of aspect 3, since typically the same points on the ground are scanned here. Of course, according to another embodiment, all three aspects can be combined. All three aspects pursue a common goal, i.e. to improve the leveling and/or control of a road construction machine (in particular a road finishing machine or a road milling machine).

## BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will be detailed subsequently referring to the appended drawings, in which:

FIG. **1***a* shows a schematic representation of a portion with sensor heads for a measuring arrangement according to embodiments;

FIG. **1***b* shows a schematic representation illustrating the cascading of multiple carriers in a measuring arrangement according to further embodiments;

FIG. **1***c*-**1***e* show schematic representations for the application of the measuring arrangement to a road finishing machine according to further embodiments;

FIG. **1***f* shows a schematic representation of a portion according to embodiments in detail;

FIG. **1***g* shows a schematic representation of a sensor head for integration according to embodiments;

FIG. **1***h*-**1***j* show schematic representations of connection options between portions or connectors and a portion;

FIG. **1***k*-**1***n* show schematic representations of distances between sensor heads at a portion;

FIGS. **1***o* and **1***p* show schematic representations of ripples generated by applied layers to illustrate different numbers of sensors;

FIGS. **1***q* to **1***v* show schematic representations of arrangements for reference measurement;

FIG. **2***a* shows a schematic representation of a layer thickness measuring system using a regression line according to an embodiment;

FIG. **2***b* shows a schematic representation of the three-dimensional space for explaining the determination of a regression line with a multitude of distance points;

FIGS. **2***c* to **2***e* show schematic representations illustrating a layer thickness measuring system based on the determination of regression lines;

FIG. **3***a* shows a schematic representation of a common control loop for screed leveling;

FIG. **3***b* shows a schematic representation of the controlled system for the screed-tow arm system;

FIG. **3***c* shows a schematic representation of a control loop structure for screed leveling according to a basic embodiment;

FIG. **3***d* shows a schematic representation of a control loop structure for screed leveling according to extended embodiments;

FIG. **3***e* shows a schematic representation illustrating the disturbance variables acting on the screed-tow arm system to explain embodiments;

FIG. **3***f* shows a schematic representation of a track-to-track installation situation;

FIG. **3***g* shows a schematic representation of rope scanning with two sensors;

FIG. **3***h* shows rope scanning with screed sensor and Big Sonic-Ski for tow point control;

FIG. **3***i* shows a schematic representation of a setup of a 3D system with total station and Big Sonic-Ski;

FIG. **3***j* shows a schematic representation of a leveling system with a total station and two prisms;

FIG. **3***k* shows a schematic representation of leveling with laser; and

FIG. **4** shows a known road finishing machine.

## DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention are explained below with reference to the enclosed drawings. Here, elements and structures having the same effect are to be provided with the same reference numerals so that the description thereof is mutually applicable or interchangeable.

### Aspect 1

Referring to aspect 1, a sensor arrangement **100** is explained below. In its simplest implementation, it comprises a carrier **110** which comprises at least one portion **111**. At least two sensors **121**, **122** are integrated (generally attached) in this portion **111**. These sensors are arranged to be spaced apart from each other. Furthermore, the carrier **110** comprises a second connecting element **132**, which is connectable to a first connecting element (not shown). The connecting element **132** and the first connecting element (not shown) are configured to form, firstly, a mechanical connection and, secondly, an electrical connection. An electrical connection is understood to mean, for example, a contact connection, a non-contact connection, such as an inductive connection. The carrier **110** and thus also the portion **111** can, for example, have a square shape (cf. carrier portion **111** of FIG. **1***f*). As can be seen in particular from FIG. **1***f*, the integrated sensor elements **121**, **122** etc. are integrated in the carrier and are all aligned in the same direction.

Assuming the installation situation of the carrier **110** parallel to the ground and further assuming that the sensor arrangement **100** is to be used to measure a distance to the ground, all sensor heads **121**, **122** etc. are oriented towards the ground. In other words, they have a scanning range extending perpendicularly to the longitudinal axis of the carrier **110** or portion **111**.

By integrating the sensors **121** and **122**, integration meaning that they can be fully embedded in the tube of the portion **111** or simply connected to it, the assembly effort is reduced considerably since only the portion **111** is mounted at the construction site and not the individual sensor heads. In other words, this means that the sensor heads **121** and **122** can be transported together with the portion **111**. The portion **111** of the carrier can be connected either to a receptacle device on the construction machine or to another portion via the interface **132**, as shown, for example, in FIG. **1***b*.

FIG. **1***b* shows a carrier **110'** with a portion **111** and a portion **112**. Each portion comprises embedded sensor heads **121** and **122**. The connection between the two portions **111** and **112** is made via connecting elements **131** and **132**, which are compatible with each other and are each arranged on the end face. For the sake of completeness, it should be noted that, according to optional embodiments, each portion **111** and **112** may also have further connecting elements **131** and **132** on the respective opposite end face.

With reference to FIGS. **1***a* and **1***b*, it should be noted that the carrier **110** can, for example, consist of one portion **111** or also of a plurality of portions **111** and **112**. Different installation situations are explained below with reference to FIGS. **1***c* and **1***d*.

FIG. **1***c* shows the portion **111**, which here comprises the connecting element **131**. The connecting element **131** is connected to a connector **135** comprising the connecting element **132**. The connector **135** is coupled to the machine. In this embodiment, to the screed **10**. The connector **135** in this embodiment extends longitudinally rearward in the direction of travel in an s-shape below the footboard **10***t* of the screed **10**. The sensor heads **121** and **122** are shown by way of example. As can be seen, these are oriented in such a way that scanning of the ground **16'** or, in this case, of the applied material layer **16'** takes place.

For example, the portion **111** may be one or two meters long, or generally in the order of 50 to 300 cm. According to further embodiments, in order to be able to scan a longer region in total, it is possible to cascade the carrier **110** by connecting two portions **111** and **112**. This is shown in FIG. **1***d*.

FIG. **1***d* shows a portion **111** connected to a portion **112** in an aligned manner. The two portions **111** and **112** together form the carrier **110** of the sensor arrangement. The sensor arrangement **110** is connected to the screed **10** via a connector **135'** such that the sensor arrangement **110** extends backwards from the screed in approximately the direction of travel. By combining two portions **111** and **112**, a longer region can be scanned while optimizing handling, particularly in assembly and disassembly. This is achieved by the fact that the portions **111** and **112** are separable from each other and can thus be stowed individually. When setting up such a long sensor arrangement **110**, only the portion **111** needs to be connected to the element **135** and the portion **112** to the portion **111**. As already explained in connection with FIGS. **1***a* and **1***b*, the connecting elements **131** and **132** are configured in such a way that, in addition to the mechanical connection, an electrical connection is also formed. In this respect, no additional wiring is needed for contacting the portion **112**, which reduces the assembly effort considerably.

FIG. **1***d* shows another exemplary installation situation at the tow arm **12**. A further holder **135'** is arranged at the tow arm **12**, which has both a first connecting element **131** and a second connecting element **132**. The sensor arrangement **110'** comprises two portions **111** and **112**, with both portion **111** being connected to the connector **135'** via its connecting element **132** and portion **112** being connected to its connecting element **131**. In other words, the element **135'**, which is firmly connected to the machine or to the tow arm **12** of

the machine, is located between the two portions **111** and **112** of the carrier. Both portions are oriented in the same way, as in the case of the sensor arrangement **110** of FIG. **1***d*, so that scanning of the ground or of the applied layer takes place.

This embodiment has thus shown that not only cascading by series connection, as in the arrangement **110**, but also cascading by common connection to a common connector **135'** is possible. Via this cascading, it is of course also possible for the measuring system to have a third portion which is arranged in series, for example. Furthermore, this embodiment has shown that different attachment positions are possible, for example on the screed **10** itself or on the tow arm **12**. It is important that the element **135'** is each fixedly connected to the screed **10** or the tow arm **12**. Screw connections, welded connections or other connections are suitable for this purpose. For example, this element **135'** can remain directly connected to the machine while the technology-carrying sensor elements/portions **111** and **112** are disassembled at night. The element **135'** of the sensor arrangement **110'** is shown in FIG. **1***e*. FIG. **1***e* shows the element **135'**, in which the portion **111** is connected on the first side and the portion **112** is connected on the second side. In this embodiment, the connecting element **135** is formed as a kind of sleeve, which corresponds in its cross-sectional shape to the cross-section of the profiled **111** and **112** (here rectangular, alternatively other e.g. round cross-section), wherein the dimensioning, in particular the internal dimensioning of the sleeve of the element **135'**, is formed in such a way that the elements **111** and **112** can be inserted. By means of the screws **135***s'* shown here, he elements **111** and **112** can be fixed. The electrical connection is not shown.

According to embodiments, the element **135'** is or can be rotated relative to the tow arm **12** to align the sensor arrangement **110** or **110'** parallel to the ground. At this point, it should be noted that this is not absolutely necessary, since computational corrections are also possible here with the principle of using a regression line, which will be explained in connection with aspect 2.

According to embodiments, the portions **111** and **112** extend substantially in alignment for both the sensor arrangement **110** and the sensor arrangement **110'** such that all sensors **121** and **122** have a substantially parallel scan lobe.

Referring to FIG. **1***f*, a portion **111** with its sensor arrangement is explained. The portion **111** may have a plurality of sensor heads **121** and **122**, such as six sensor heads in this case. These are marked with the reference numerals **121** to **126**. For example, the arrangement can be equidistant, although another arrangement may also be practical, as will be explained below with reference to FIG. **1***m*. The number can also vary accordingly (cf. explanations in connection with FIGS. **1***k* and **1***l*).

The sensor heads **121** to **126** are embedded on one side of the profile, which is rectangular in this case, as shown in FIG. **1***f* and in FIG. **1***g*. FIG. **1***g* shows an exemplary profile of 60×80 mm, with a sensor head **126** embedded on the narrower side **60**. This can, for example, be clicked or screwed into place. According to embodiments, the sensor head **126** is approximately flush, i.e. +/−3 mm or +/−10 mm or +/−20 mm, with the surface of the profile.

According to embodiments, the sensor head is an ultrasonic sensor, although other sensor technologies, such as lasers or capacitive sensors, can also be used. Different measuring principles can also be used for the different sensor heads per portion **111** or per sensor arrangement **110**.

FIG. **1***h* shows the two portions **111** and **112** connected to each other by a connector **138**. The portions **111** and **112** are simple profiles which are inserted into the connector **138** and connected by means of the eccentric **138***e* on each side. The profiles have the connecting elements **131** and **132** at the corresponding end faces at which the connection to the connector **138** is made, the connector **138** having the corresponding counterparts to form the electrical connection in addition to the mechanical connection. In this embodiment, the electrical connector may be realized, for example, by a plug integrated in the connector **138** and closed in the longitudinal direction of the portions **111** and **112**.

Another embodiment of a slide-in connector is shown in FIG. **1***i*. Here, a modified connecting element **138'** with the eccentric **138***e* is shown, into which the portion **111** is inserted. The connecting element **138'** may, for example, belong to the further portion of the carrier or may also be permanently connected to the machine.

According to another embodiment, it would also be conceivable for, instead of the eccentric **138***e*, a screw connection to be carried out with a knurled screw, as shown in FIG. **1***e*. The common feature is that the profile **111** or **112** is inserted and fixed by means of a further means, such as an eccentric or a screw. It would also be possible to use some sort of quick-release fastener, as is common in bicycles, or a bayonet-type fastener. It should be noted at this point that the portion **111** can be implemented, for example, with a closure cap **111***v* on one end face.

FIG. **1***j* illustrates another connection concept. In this embodiment, the portion **112** has a kind of hook **131***h'* as a connecting element **131'** so that the hook is connectable to an engaging portion of the connecting element **132'**. The engagement portion of the member **132'** is provided with the reference numeral **132***e'*. These two members establish a mechanical connection by performing a rotor movement of the portion **112** with respect to the further member to which the portion **112** is to be connected. The electrical connection may also be carried out in this rotor connection, for example by contact at the end faces. The end face limits the rotor movement.

The element **112** has a cap on the opposite end face. The cap is provided with the reference numeral **112***v*.

It should also be noted at this point that other connection options are also conceivable. For example, the respective connecting element can also have guides extending orthogonally to the longitudinal direction so that a kind of dovetail connection is formed.

All these mentioned connections have in common that a portion at a fastening element or several portions can be connected to one another, wherein an electrical connection is formed in addition to the mechanical connection. Also, the angular orientation of the longitudinal portion is fixed by the connector.

As explained above, each portion may comprise a plurality of sensor elements **121** etc. In FIG. **1***k*, it is assumed that the portion **100** has a length of 2 m (200 cm) and the sensor heads **121-126** (here six sensor heads) are distributed evenly. This results in a distance of 33 cm between the sensor heads, where 33/2 cm are provided from the end face to the first sensor head **121** and to the last sensor head **126**. FIG. **11** shows a portion **100** of length 2 m (200 cm), where five sensor heads **121-125** are provided. The distance is again equidistant so that a distance between the sensor heads of 40 cm and from the end face to the first or last sensor head **121/125** of 20 cm is obtained.

As shown in FIGS. **1***o* and **1***p*, the number of sensor heads has a significant influence on the possible control. FIG. **10**

shows a comparison between a classic Big Sonic-Ski (Big Ski for short) with a 12 m extension using three, four and five sensors. As can be seen, the Big Sonic-Ski with three sensors has problems in the 6 m range, the Big Sonic-Ski with four sensors has problems in the 4 m range, and the Big Sonic-Ski with five sensors has problems in the 3 m range. The same problems are experienced by the Big Sonic-Ski with three sensors. By increasing the sensor density, these high-frequency problems (compared to vibration) can be reduced in the range of 20 m etc. The improvement by using the sensor arrangement described in FIG. **1** (and according to the invention) is shown in FIG. **1***p*. Here, an 8 m carrier is assumed to have three to six sensors. As the number of sensors increases, the control gaps become more high-frequency, but this is less critical because the probability of high-frequency interference is lower.

In summary, an increase in sensor density in the longitudinal direction offers a quality advantage. All in all, it is considered that embodiments have a sensor arrangement with a length of at least 4 m, i.e. comprising two portions. Even better qualities can be achieved with 6 m or 8 m sensor arrangements.

In order to improve also high-frequency gaps or in general gaps resulting from harmonic vibrations, a non-equidistant sensor pattern per portion can also be used according to further embodiments. Such examples are shown in FIG. **1***m* for a distance with five sensor heads **121**-**125**. Here, the distance increases from 20 cm between the end face and the first sensor **121**. For example, the distances are 32, 40, 46, and 58, and 4 cm.

FIG. **1***n* shows a further representation, wherein equidistant sensors with a distance of 44 cm are again used here, but the distance between the end face and the first sensor **121** is selected in such a way that an equidistance is also maintained over two portions. Here, the portion between the end face and the first sensor is selected in such a way that half of the distance is present between the further sensor or, in particular, the sensors **121** and **122**.

Possible implementation examples of reference sensors are explained below with reference to FIG. **1***q*-*v*. Ultrasonic sensors are often subject to drift, e.g. as a result of ambient temperatures, and a reference measurement is to be performed for this. A reference measurement is made, for example, by measuring a known distance with an ultrasonic sensor and using this reference signal as a calibration value based on the measurement signal, typically a time period between transmission and reception of the response signal. FIG. **1***q* shows a portion **111** having sensor heads **121** etc. One or each sensor head has a bracket **171** arranged at a defined distance in front of the sensor **121**. This bracket **171** is located at least partially in the entire measurement field and can be folded in according to embodiments or can also be of rigid design. The bracket **171** reflects the measurement signal, as shown here by means of the dashed line.

Another variation is shown in FIG. **1***r*. Here, a bracket is also provided at a sensor, here the sensor **125**. The bracket has a reflector **172**. According to embodiments, the bracket is integrated in the holder **131'**, here a hook holder (cf. FIG. **1***j*). The reflector **172** is located at a defined distance from the sensor **126** and can thus be used for reference measurement.

FIG. **1***s* shows a further variation, wherein a further reflector **173** is provided in a laterally arranged bracket which extends approximately perpendicularly to the longitudinal extension of the portion **111**. This reflector **173** is arranged at a distance from the sensors **126**, but serves not only as a reference for the closest sensor **126**, but also for the sensors **125**, . . . **121** arranged next to it. According to embodiments, the reflector **173** may be arranged at an angle, e.g. 45° with respect to the measuring direction of the individual sensor heads **121** to **126**. According to further embodiments, the reflector surface **173** may be curved to serve as a reflector for all channels **121** to **126**. As shown herein, the bracket connecting the reflector **173** to the portion **111** may be either attached directly to the portion **111** or may be integrated in the connecting element, as shown, for example, in connection with FIG. **1***r*.

FIG. **1***t* is essentially similar to the embodiment in FIG. **1***s*, although here the reflector **174** has an active mirror which aligns itself accordingly depending on which channel (sensor head) is to be calibrated.

Referring to the embodiments of FIGS. **1***s* and **1***t*, it should be noted that, for example, sensor heads **121** to **126** can be calibrated one after the other so as not to interfere with one another.

In accordance with further embodiments, it would also be conceivable for the active reflector **174** to be an active transmitter unit, which then directs an ultrasonic signal to the receivers **121** to **126**.

In the embodiment of FIG. **1***u*, it is assumed that an ultrasonic sensor **176** is used for reference measurement by means of a bracket **175** arranged below the sensor heads **121** to **126**. Below here means between the carrier/portion **111** and the road surface. The ultrasonic sensor **176** is arranged parallel to the carrier/portion **111** and can be arranged, for example by means of an additional reflector **177**, on the other end face or also between the end faces, for example in the center (cf. dashed element **177'**).

According to another variation shown in FIG. **1***v*, the active transmitter **176** arranged on the bracket **175** can cooperate with an active receiver **178** arranged on a bracket **175** on the other end face.

All the embodiments have in common that the reference measurement takes place in the region of the ultrasonic sensors **121** to **126**. This has the advantage that the same ambient conditions prevail here, e.g. ambient temperature and infrared radiation.

All possibilities of reference measurement by means of reflectors arranged on the end faces, by means of active transmitters or receivers arranged on the end faces, or by means of transmitters or receivers arranged on the end faces, which form a parallel signal, for example, can be implemented in such a way that the connecting elements, which are welded to the profile or arranged on the profile in general, for example, have these reflectors or transmitters integrated. In this context, reference is made to FIG. **1***h*, which shows a reflector comparable to the reflector **172** of FIG. **1***r* integrated into the profile connector. In this respect, the element for carrying out the reference measurement is not part of the portion **111** or **112** at all, but of the connector **138**. Another variation, which follows, for example, the measurement principle shown in FIG. **1***v* with active transmitter **176** and active receiver **178**, is shown in FIG. **1***i*. An active transmitter **176** is integrated here into the element **138'**, while the receiver **178** is integrated into the closure cap **111***v*. In this embodiment, it would of course also be conceivable for a reflector **177** to be used instead of the receiver **178**. A similar variation is shown in FIG. **1***j*. The transmitter **176** here is integrated into the element **131'**, while the receiver or reflector **177** and **178** is integrated into the closure cap **112***v*. Of course, it would also be conceivable for **176** to be interchanged with **177**/**178** in the embodiments of FIGS. **1***i* and **1***j*.

In all embodiments, it is advantageous for measurements of the sensor heads to be performed substantially simultaneously (synchronous measurement within a time window, e.g. within a time window of 3 s, 1 s, 0.5 s, 0.1 s or smaller). That is, it is advantageous for all the sensor heads arranged in the measuring system to perform measurements essentially simultaneously. This means that a simultaneous measurement in principle provides a snapshot of, for example, the ground or reference profile (the layer already applied or the ground for the layer to be applied) and the reference measurement(s) under the same conditions (for example, environmental conditions such as ambient temperature). Thus, a correct reference profile or correct profile of the ground is acquired from all the sensor heads in all the portions and all the carriers of the measuring system. A substantially simultaneous measurement is also of advantage with regard to a high measurement rate (sampling rate), as is nowadays needed for leveling in road construction (for example, height leveling of the screed).

Referring to FIG. **1***g*, another feature is explained. In FIG. **1***g*, an end face LED **181** is also indicated. This can indicate, for example by color coding or flashing, whether the electrical connections between portions or from portion to machine are correct. Furthermore, information such as readjustments needed can also be displayed. Furthermore, it would also be conceivable for the LED, when arranged, for example, at the ending end face in FIG. **1***d* of the measuring arrangement **110**, to give signals regarding the distance to a vehicle, such as a roller, driving behind it. For this purpose, according to embodiments, a further distance sensor can also be aligned in the other direction in the end face similar to the distance sensor for reference measurement **176**, which then measures the distance to a following vehicle.

According to further embodiments, instead of the LED, a complex display such as an LCD may be provided, for example to display text and/or symbols.

## Aspect 2

A measuring system **200** which uses a regression line to determine a position is explained below.

As in the embodiment of FIG. **2***a*, the measuring system **200** comprises a carrier **210** arranged, for example, on a component such as the screed **10** of the construction machine. As shown here, the component **10** is tilted, for example, by an angle α. Exemplarily, the carrier extends backwardly or even forwardly (not shown) from the component **10**. The carrier **10** is further fixed to the component and thus changes its angular orientation in space according to the angle α.

Three sensor heads **221** and **222** and **223** are provided on the carrier **210**. Although it is not important for the calculation at first, it should be noted here that the sensor head **221** is located closer to the screed edge **10***k*, which represents a pivot point **10** of the screed, than the sensor **223**. The sensor head **222** is located in the middle or in between. For example, the distance to the perpendicular foot point on the screed edge **10***k* may be denoted by A, while the distance on the perpendicular foot point of the screed edge **10***k* to the sensor **223** is denoted by B. In general, it should be noted that, as an alternative to the pivot point around the screed rear edge **10***k*, the screed **10** can also have a different pivot point, e.g. in front of the screed rear edge **10***k* (in particular if it rests on hot asphalt). In this case, for example, the distances to the pivot point are then taken into account accordingly.

The sensors **221**, **222** and **223** are arranged substantially parallel and measure a distance from the carrier **110** to the ground, in this case the applied layer **16'**.

Based on the angle α, the distance H**1** is greater than the distance H**3**. The sensor values can, for example, be recorded in a two-dimensional space, here height over distance. Based on the sensor values, it can be seen that the regression line RG also runs according to the angle α. If it is in the two-dimensional space, the regression line RG can be determined in such a way that the angle α can be determined computationally. By determining the angle α, the position of the component **10** relative to the ground is also known.

It should be noted at this point that the position a does not necessarily have to be an absolute position, but can in particular be a relative position with respect to the ground.

Referring to the distances A and B, it should be noted that if there are two sensor values, these do not matter, it is much more important that the position of the sensors **221**, **222** and **223** to one another is known. Of course, the same is also true for more than two sensors to determine the height values in the two-dimensional space.

If, for example, the screed height changes, the values H**1** and H also change3, wherein, starting from a parallel displacement, the angle α remains constant. Thus, if there are slight variations in the values due to vibrations, for example, these values can be plotted in the common space and a regression line RG can be determined. This represents averaging. The use of more than three sensors also results in averaging if all sensors are arranged exactly on the carrier **210**.

Referring to FIG. **2***b*, the determination of the regression line RG for a point cloud is explained. In this embodiment, it is assumed that more than two sensors are provided. For example, the sensor array from aspect 1 can be used. The deviations, as shown here based on the height points H**1** to Hn, can originate, for example, due to unevenness in the ground. Essentially, however, the height values increase from a to n, so that this can be conveyed here in the regression line RG. For example, the regression line RG is placed in such a way that the distance between the regression line RG, represented here by small arrows, and the measuring points becomes minimal in total.

Here, too, the regression line is angled with respect to the distance axis, e.g. by the angle α. This position can be determined and gives a conclusion as so the angle of the component.

For example, if the carrier of FIG. **2***a* with sensors **221**, **222** and **223** is attached to the screed and arranged in the longitudinal direction, the roll angle of the screed about its longitudinal axis can be determined. If, in addition to the longitudinal component, there is a transverse component, a combination of the roll angle and the transverse inclination angle is determined. Knowing the transverse component to the longitudinal component, these two angles can be separated. The transverse component can be determined, for example, using the carrier from FIG. **2***a* with sensors **221**, **222** and **223** if it is arranged in the longitudinal direction of the screed (i.e. transverse to the direction of travel of the machine).

According to embodiments, the carrier runs without any angular offset with respect to the component. An offset can also be taken into account. To determine the offset, for example, a calibration can be performed at the beginning or an adjustment can be made with an optional angle sensor, such as an inclination sensor.

According to embodiments, instead of attaching the carrier to the screed, the screed could also be attached to the tow arm, for example. An example of such an attachment is explained in aspect 1, as it involves attaching a carrier comprising a plurality of portions.

This carrier has a plurality of integrated sensors, which then corresponds to an averaging regression line according to the embodiment of FIG. **2***b*.

Referring to FIG. **2***c*, a layer thickness determination by means of the regression line is explained below.

FIG. **2***c* shows the use of the sensors **221** and **223** by means of the carrier **210** and the use of another carrier **215** which houses the sensors **225** and **227**. As in FIG. **2***a*, the sensor array **210** is arranged behind the screed, while the sensor array **215** is arranged in front of the screed. Of course, an interchanged arrangement would also be conceivable. It is assumed that both extend in the longitudinal direction.

The resulting sensor values H**1**, H**3**, H**4** and H**6** are plotted in FIG. **2***d* in the two-dimensional space. This results in the two regression lines RG**1** and RG**2**. If both regression lines RG**1** and RG**2** are now tilted about the screed center of rotation, namely the screed rear edge **10***k*, the regression lines are mapped to the corresponding RG**1'** and RG**2'**, as shown in FIG. **2***e*. The axis distance in FIG. **2***e* is parallel to the ground or the reference against which measurements are made. The tilted regression lines RG**1'** and RG**2'** are now no longer in line with each other as in FIG. **2***d*, but have an offset V. This offset V results from the fact that the array **210** associated with the regression line RG**1** measures to the layer **16'** to be applied, while the sensor array **215** measures to the ground **17**. In this respect, this offset depends on the thickness of the layer **16'** to be applied. Conversely, this means that the layer thickness can be determined, i.e. calculated, by means of this approach.

According to embodiments, the distances A, B, C and D between the respective sensor **221**, **223**, **225** and **227** and the perpendicular foot point on the screed edge **10***k* in the rotation are used to perform the rotation.

In the above examples, it has to be kept in mind that when measuring with ultrasound, the perpendicular to the ground is measured and not the perpendicular, relative to the carrier, to the ground. In other words, the variation shown represents, for example, a measurement with a laser or the like.

For all measuring systems explained above, comparable (same) mounting heights were assumed, wherein it should be noted that these can also vary and are then corrected by calculation afterwards.

## Aspect 3

FIG. **3***a* shows a common control loop **300** (evenness control loop) used for leveling the screed **10**, which is pulled via the tow arm **12**. The tow arm **12** is connected fixedly, or at least during operation connected fixedly, to the screed **10**. The screed is towed by a tractor (not shown), for which purpose the tow arm **12** is connected to the tractor via the tow point. The tow point is typically adjustable in height, as illustrated here by the arrow **14**. This height adjustment is controlled by the evenness control loop **300**.

For the sake of completeness, it should be noted that the screed smooths the asphalt or material for the layer **16'** to be applied, which is provided by the auger **18** in front of the screed (cf. material **16**).

The evenness control loop **300** comprises an evenness controller **310** which controls the toe point cylinder (cf. reference numeral **14**) based on a set-versus-actual point comparison **320**. The result is a changed height, which is detected by means of the height sensor **330**. The height sensor signal of the height sensor **330** is then in turn fed to the set-versus-actual point comparison **320**. Optionally, a filter **335** may also be provided. This filter is implemented either as a low-pass filter, low-pass filter with low/increased cut-off frequency, band-pass filter or high-pass filter, depending on how the transmission behavior is to be corrected. Other frequency filters, such as Chebyshev filters or similar, are also conceivable in this context.

The transmission behavior is influenced by both the tow point cylinder and the screed itself. The transmission behavior of the tow point cylinder can be described using an $IT_1$ control loop (see block **342**). The transmission behavior of the screed can be described as follows: in sensor position represented by a P-behavior (cf. **344**). The screed itself can be represented by a $PT_2$ element (cf. **346**).

At this point, it should be noted that in the case of direct height control with the control loop **300**, the transmission behavior **342** and **344** is taken into account, but not **346**, since this is very inert. In this respect, the behavior **346** is to be readjusted over time. The transmission behavior **344** is therefore also taken into account, since a change in the height position at the toe point **14** ZP (cf. reference numeral **14**) also leads to a change in the height position at the scan point in the region of the auger **18**.

Previous levelling systems for the road finishing machine attempt to compensate for all the disturbance variables via a single control loop. The problem here, however, is that there are two dominant and significantly different time constants in the "screed-tow arm" control loop, which needs to be reacted to separately and differently in order to optimally compensate for the influencing disturbance variables. While the screed itself has a very inert behavior and thus a comparatively high time constant in the range of several seconds, the tow point, which is usually controlled by a hydraulic cylinder, has a very small time constant in the range of milliseconds.

As already indicated above, the transmission behavior of the screed-tow arm system can be described as a kind of series connection of transmission elements:

Tow point cylinder with an IT1 behavior

Height sensor position represented by a P behavior

The screed itself described by a PT2 member

FIG. **3***b* illustrates the transmission behavior of the controlled system from the rear edge of the screed to the cylinder interpreted in this way. FIG. **3***b* again shows the screed **10**, which is pulled or adjusted in height via the tow arm **12** at the tow point **14** ZP by means of the tow point cylinder **14**.

FIG. **3***b* is further intended to illustrate that the usual scan point with respect to the reference does not reflect the behavior of the entire controlled system **342-346**, from a control point of view. This also makes it clear that with the current control systems, there is no direct height control of the rear edge of the screed **10***k*. The result is that, due to disturbance variables acting over a certain period of time, a slight tilting takes place above the scanning point between the rear edge **10***k* and the tow point **14** ZP and thus a change in height occurs at the rear edge of the screed **10***k*.

Based on this common control loop structure used in practice for the height leveling of the screed **10**, the improved and optimized extension of the screed leveling is explained below.

The basic idea for optimizing the height levelling of the screed **10** is the targeted monitoring of the road finishing machine screed and, in particular, of the screed rear edge by means of an additional control loop or the implementation of

a control loop superimposition to the existing height levelling. The control loop for normal height levelling functions as a subordinate control loop. This new control loop structure can be applied to all height levelling tasks and will be considered in detail below.

This control loop structure is shown in FIG. **3***c*. The control loop **350** shown here comprises two individual control loops **360** and **370**. The control loop **360** is referred to as the first control loop or superimposed control loop. The control loop **370** as the second control loop. The control loop **370** is similar to the control loop **300** as explained with reference to FIG. **3***a*, although the sensor **330** is positioned differently (cf. reference character **331**). The sensor **331** is provided in the region of the tow point **14** ZP and no longer in the region of the auger **18** (cf. arrangement FIG. **3***b*). Otherwise, the control loop **370** corresponds to the control loop **300**, i.e. includes the comparison **320**, the evenness controller **310** as well as the optional filter **335**. A significant difference, starting from the positioning of the height sensor, is that in the control loop **370** the transmission behavior of the screed **344** no longer has to be taken into account, but only the transmission behavior of the tow point cylinder (cf. reference numeral **342**). The behavior of the screed, described by $PT_2$ (cf. reference numeral **346**), is also taken into account with the control loop **360**.

The control loop **360** also includes a height sensor **362** and an optional filter **364**. The sensor **362** is located in the region of the screed **10** or, for example, in the region of the rear edge of the screed **10**. The response of the point **10***k* to a change in height at the tow point **14** ZP (cf. reference numeral **14**) is relatively inert. This becomes quite clear when looking at the arrangement of the screed **10**, tow arm **12** and tow point **14** ZP, since the height cylinder **14** shifts the tow point **14** ZP around the pivot point **10***k*, so that a change in height only occurs gradually. This behavior is reproduced by means of the Model Predictive Control **365**. The input variable for the MPC **365** is the result of a set-versus-actual value comparison (cf. reference numeral **367**), wherein the same signal of the sensor **362** is used as the actual signal. The result of the MPC is a target signal which serves as an input variable for the comparison **320**. Now that the structure has been explained, the mode of functioning will be discussed.

Based on these facts, the control loop **370**, which is shown in FIG. **3***a*, is extended by a superimposed control loop **360**, which is shown in FIG. **3***d*. This measure changes the structure of the control loop **350** in such a way that the disturbance variables acting on the tow point **14** ZP and the screed **10** can be compensated separately. The superimposed control loop compensates for the disturbance variables acting on the screed **10** and the subordinate control loop **360** compensates for the disturbance variables changing the height of the tow point. The control system **350** structured in this way can be optimized separately, resulting in an improved overall control behavior.

A further optimization of the control loop structure results from the fact that the scan point tends to be shifted from the height sensor for the subordinate evenness control loop **370** towards the tow point **14** ZP.

Based on this complex embodiment, a simplified variation will now be discussed with reference to FIG. **3***d*.

FIG. **3***d* shows a control loop **350** composed of two control loops **370** and **360**. Each control loop comprises at least one sensor, which in the case of the control loop **360** is the height sensor **362**, while in the case of the control loop **370** it is the tow point sensor **331**.

As the name implies and as explained above, the sensors are arranged in the region of the tow point (cf. sensor **331**) and at the screed (cf. sensor **361**).

Each control loop also includes a corresponding processor, which outputs the control signal for the tow point cylinder based on the actual value of sensors **331** and **362** and a setpoint. The processors are denoted by **379** and **369**. According to embodiments, the processors **369** and **379** can also be combined to form one processor, which then receives the actual signals from the two sensors **331** and **362** and first processes these separately in order to then output the common control signal.

The separate consideration of acting disturbance variables for the controlled system **346** screed-tow arm is also of decisive importance for the setup of the control loops **350**. FIG. **3***e* shows the different disturbance variables in the screed-tow arm system.

While the disturbance variables at the tow point are compensated by the subordinate control loop **370** (evenness control loop), the disturbance variables of the screed **10** are compensated by the superimposed control loop **360**. Due to the different transfer functions (see also FIG. **3***b*) of the partial control loop tow point (IT1) and the partial control loop screed (PT2), the controllers used for this purpose are also designed and optimized differently by their structure.

For the subordinate control loop **370**, control deviations are compensated extremely quickly, while the controller for the superimposed control loop **360** performs the compensation of control deviations rather slowly, taking into account the knowledge of influencing disturbance variables. As an example of disturbance variables which influence the floating behavior of the screed **10**, the effect of material temperature changes can be mentioned here. If a temperature change of the material is already known before a temperature-dependent effect on the screed height arises, the controller can avoid or reduce a height deviation of the screed on the basis of a model. The model of the screed **10** which describes the dependence of a height change due to material temperature changes is to be known. This would also be a typical example of an MPC controller for the superimposed control loop **360**.

Different cases of application of the control loop structure **350** are explained below.

Based on the control loop structure **350** in FIG. **3***d*, the various cases of application will be examined below by way of example. However, the basic structure of the control loop remains the same for all applications. Only the sensor implementation for the rear edge of the screed or the tow point may change. The different installation situations can be named as follows:

Track to track
Scanning at the curb
Rope scanning
Scanning at a line (tunneling)
Installation without reference (Big Sonic-Ski)
3D installation with total station
3D installation with GNSS
Cross tilt screed
Scanning with laser

Of course, a different scanning constellation can also be selected for the respective opposite side so that a plurality of installation situations can be represented with the optimized control loop **350**. In addition, further optimizations can be realized with the help of the new control loop structure **350**. These include:

Start-up after road finishing machine stop
Daily beginning (new beginning)

Integration Model Predictive Control

In the following, some cases of application for the new control loop structure **350** will be described as examples.

If height scanning is done from an existing or previously laid asphalt track (paving track to track), the following sensors can be used for the screed rear edge:

Sonic ski

Single-head sonic with and without reference signal

Laser scanner

Mechanical rotary encoders

The single-head sonic without reference can be used because the measuring distance to the existing asphalt track at the rear edge of the screed can be minimized. For this reason, the measurement error is greatly reduced compared to large distances. A minimization of the measuring distance is possible because the measuring distance to the ground is approximately the same. In this application, the/all sensors look at the ground as focused as possible.

The following sensors are used for the tow point:

Sonic-Ski

Laser scanner

Big Sonic-Ski (short: Big Ski)

FIG. **3***f* shows the mounting region and thus also the possible and useful scanning positions to realize the control loop structure.

FIG. **3***f* shows the road finishing machine from above with the screed **10**, the applied layer **16'** or existing layer **16***, the auger **18** and the tractor **11**. The screed is connected to the tow point **14** ZP via the tow arm **12**.

According to a first variation, a so-called Big Sonic-Ski (in short: Big Ski, cf. aspect 1) **100** can be connected to the tow arm **14** or also to the screed **10** (not shown). The Big Sonic-Ski has, for example, the sensor **361** provided in the region of the rear edge of the screed **10***k*. At the level of the tow point, the sensor **331** may also be arranged on the Big Sonic-Ski **100**.

According to a further embodiment, the scanning of the screed's rear edge for the screed control loop and the scanning for the tow point control loop can also be performed on the side of an existing asphalt track **16***.

Here, a Sonic-Ski **331*** is provided via a side plate **10***s* for scanning at the height of the tow point **14** ZP. A screed rear edge sensor **361*** is also provided on the side plate. As shown, the Sonic-Ski **331*** is offset slightly with its scanning region outside the ground so as to scan the existing asphalt track **16***.

The purpose of arranging the sensor **331*** on the side of the existing asphalt track **16*** is to use the existing asphalt track as a reference. In this respect, the sensor **331*** is used to scan the distance to the existing asphalt track **16***. The purpose of using the tow point control loop to scan the existing asphalt track **16*** is to directly compensate for disturbance variables (e.g. material under the crawler track of the tractor) which act on the tow point. In contrast, the sensor **361*** is directed at the existing asphalt layer **16*** and monitors the elevation of the screed in relation to the existing asphalt track **16***, compensating for deviations from the set target value of the superimposed control loop **360**.

With reference to FIG. **3***g*, a rope scanning system is now explained. FIG. **3***g* shows a road finishing machine with a tractor **11**, a screed **10**, a screed rear edge **10***k*. The screed **10** is connected to the road finishing machine **11** by a tow arm **12**. The Big Sonic-Ski **100** with three sensors is provided on one of the tow arms **12**. The sensors are denoted by the reference numeral **110** as an example, and, depending on the application, can be equally distributed along the Big Sonic-Ski **100** or also arranged in the region of the tow point **14** ZP or also in the region of the rear edge of the screed **10***k*. Alternatively or additively to a Big Sonic-Ski, a sensor system may also be provided over the side plate **10***s* of the screed **10**. For example, a screed sensor **361*** may be provided, as well as a tow point sensor **331***. Both are directed to a rope **16***s* to scan the rope **16***s*.

Rope scanning at the rear edge of the screed **10***k* can be performed without contact using an ultrasonic sensor (Sonic-Ski) or a mechanical encoder, as is common practice with the scanning methods currently in use.

The sensors **331***, **361*** are guided over the reference rope **16***s* with a corresponding sensor holder **10***k*. The system deviation measured relative to the reference rope **16***s* at the rear edge of the screed **10***k* also provides information on the installed evenness when viewed over the path.

For the region from the tow point **14** ZP, there are several ways to obtain height information for the control loop. In the following, 2 possibilities are shown.

A second height sensor (Sonic-Ski) can be guided over the rope via a further sensor holder. Alternatively, a Big Sonic-Ski system (Big Ski in short) can be used as a tow arm sensor. See FIG. **3***h*.

FIG. **3***h* shows the comparable setup as FIG. **3***g* of the road finishing machine **11** with a screed **10**. The sensor **361*** is used as the screed sensor on the left side. The Big Sonic-Ski **100**R is used as the tow point sensor on the left side. As already explained, it is permanently connected to the tow arm **12** and has a plurality of sensors **110**.

With regard to the Big Sonic-Ski **100**, it should be noted that, as already explained in connection with aspect 1, one or more sensors, e.g. equally distributed, are arranged in front of and behind the screed **10**. With respect to further details in this regard, reference is made to the explanation of aspect 1.

Referring to FIG. **3***i*, 3D leveling with a total station is now explained. FIG. **3***i* shows the screed **10** with the screed rear edge **10***k*, the tow arm **12**, which is connected to the tow cylinder **14** at the tow point **14** ZP. In addition, a Big Sonic-Ski **100** connected to the tow arm **12** is also provided. The Big Sonic-Ski **100** includes three distance sensors **110**, which together determine the distance at the tow point **14** ZP in this embodiment. The screed rear edge **10***k* is monitored using a total station **50** and a reflector **52** attached to the screed. This sensor consisting of elements **50+52** is referred to as a 3D sensor.

Height determination at the rear edge of the screed with a 3D sensor **50+52** has the advantage that it is also possible to monitor the absolute height position of the asphalt track to be paved. 3D levelling with a total station **50** consists of a prism **52** mounted on the road finishing machine **11** or screed **10** in such a way that it is visible to the total station **50**. The total station **50** then determines the 3D position of the prism in space and transmits this information to the 3D control system on the road finishing machine by radio.

A major disadvantage of 3D control is that the installed height level is to be checked again and again. In practice, this task is performed by a surveyor who checks the installed height level with an additional total station **50** and, if needed, makes appropriate corrections manually. This is needed because the mounting location of the prism (3D point in space precisely determined by the total station via the reflection of a laser beam) is not located at the rear edge of the screed, but, as is usually the case with other height sensors, at the tow arm at the height of the screed auger. This results in a change of the elevation at the rear edge of the screed over a certain period of time, which the surveyor then has to correct again.

If considering the improved control loop structure **350**, there are also optimization possibilities for 3D control with a total station.

The control of the built-in height measurement could be avoided by placing the height sensor (prism) on the screed rear edge **10***k*. Here, the sensor acts as a height sensor for the screed and is thus used in the superimposed control loop **360** as a supplier of the height information. For example, a Big Sonic-Ski system (Big Ski in short) is then located at the tow point, which supplies the height value for the subordinate control loop **370**.

A further advantage arises if wanting to level both sides of the screed **10** via a total station **50** in connection with a prism **52** (cf. FIG. **3***i*). Without the extended and optimized control loop structure **350**, two total stations **50** are needed for leveling (one total station for each side). This is needed because in this constellation the scan rate of the 3D height measurement has to be high in order to compensate for all influencing disturbance variables. With the expanded and optimized control loop structure **350**, the scan rate can be reduced to such an extent that one total station is sufficient for both sides, which then continuously and successively determines the left prism **521** and the right prism **52***r* in the position at the screed rear edge **10***k*.

Referring to FIG. **3***k*, instead of the left Big Sonic-Ski **100** L which served as the tow point control in FIG. **3***j*, the tow point sensor is now also implemented by a laser sensor. A laser transmitter **54** maps a height reference which can be received at the screed **10** via the receivers **56***z* at the tow point **14** ZP and **56***b*.

In principle, the new control loop structure **350** can also be applied when using a laser plane as a height reference. In this case, a laser receiver is attached to both the tow arm and the rear edge of the screed, which in both cases operates as a height sensor. In this constellation, the projected laser plane exactly represents the desired position of the road with a corresponding height offset.

FIG. **3***k* shows the basic setup of leveling with a laser height reference on the left side. In the example, the right side is leveled with a Big Sonic-Ski system **100**. Alternatively, depending on the installation situation, other measuring elements such as inclination sensors or Sonic Ski, can be used for leveling the screed.

Referring to FIG. **3***d*, note that the Model Predictive Control extends the control loop structure as follows.

A further improvement for the control system results from the fact that the controller for the superimposed control loop, whose associated sensor is installed near the rear edge of the screed, also takes the respective process state into account. In principle, a control value is assigned to each state, which is also responsible for the calculation of the controller output. Furthermore, the process state is predetermined with the help of a process model.

The process model is the actual foundation of Model Predictive Control, wherein the model comprehensively captures the process dynamics and can thus calculate the predictions of the future process state. The process model is needed to calculate the predicted output variables in a future instance. The various strategies of MPC can use numerous models to show the relationship between the output variables and the measurable input variables.

In the following, additional embodiments and aspects of the invention will be described which can be used individually or in combination with any of the features and functionalities and details described herein.

A first aspect relates to a measuring system **200** for a construction machine, wherein the measuring system **200** comprises a carrier connectable to a component of the construction machine, wherein the measuring system **200** comprises: first, second and third sensor heads that are connected to the carrier **210** and are configured to measure a first distance from the first sensor head to a ground or reference to obtain a first measuring value, and to measure a second distance from the second sensor head to a ground or reference to obtain a second measuring value, and to measure a third distance from the third sensor head to a ground or reference to obtain a third measuring value; a calculation unit that is configured to determine, based on the first measuring value, the second measuring value and the third measuring value, a regression line RG together with a slope of the regression line relative to the ground or the reference and to determine, based on the slope, an angle that describes the slope of the regression line RG and the position of the component of the construction machine relative to the ground or the reference; wherein the first, second and third sensor heads have a substantially parallel orientation, such that a scanning area extending in parallel or substantially in parallel is formed.

A second aspect relates to a measuring system **200** according to aspect 1, wherein the component includes a tow arm **12** or a screed **10** and/or a screed **10** connected fixedly via the tow arm **12**, rigidly and/or at least rigidly during the working process having a fixedly defined relationship between component and measuring system **200** or a relationship at least fixedly defined during the working process.

A third aspect relates to a measuring system **200** according to aspect 1 or 2, wherein the carrier **210** extends in front of the screed **10**.

A fourth aspect relates to a measuring system **200** according to aspect 1, 2 or 3, wherein the measuring system comprises a further first, further second and further third sensor head that are connected to a further carrier **215** and configured to measure a further first distance from the further first sensor head to the ground or to the reference to obtain a further first measuring value, and to measure a further second distance from the further second sensor head to the ground or to the reference to obtain a further second measuring value, and to measure a further third distance from the further third sensor head to the ground or to the reference to obtain a further third measuring value; wherein the calculation unit is configured to determine, based on the further first, further second and further third measuring value, a further regression line RG**2** together with a slope of the further regression line RG**2** relative to the ground or the reference and to determine, based on the slope, an angle $\alpha$ describing the slope of the further regression line RG**2** and the position of the component of the construction machine relative to the ground.

A fifth aspect relates to a measuring system **200** according to aspect 3, wherein the further carrier **215** extends behind the screed **10**.

A sixth aspect relates to a measuring system **200** according to aspect 3 or 4, wherein the carrier **210** extends in front of the screed **10** and/or wherein the calculation unit is configured to determine a layer thickness based on the regression line RG and the further regression line RG**2**.

A seventh aspect relates to a measuring system **200** according to one of aspects 1 to 6, wherein the carrier **210** extends along a longitudinal axis of the construction machine.

An eighth aspect relates to a measuring system **200** according to aspect 7, wherein the measuring system is configured to determine an angle $\alpha$ relative to the ground in the longitudinal direction of the measuring system, a rota-

tion of a screed **10** around a longitudinal axis of the screed **10** and/or a longitudinal inclination of the chassis.

A ninth aspect relates to a measuring system **200** according to one of aspects 1 to 8, wherein the carrier **210** or a further carrier **215** extends in an oblique or translational manner to a longitudinal axis of the screed **10**.

A tenth aspect relates to a measuring system **200** according to aspect 9, wherein the measuring system **200** is configured to determine an angle α relative to the ground in transversal direction, a tilting of the screed **10** and/or a transversal inclination of the chassis.

An eleventh aspect relates to a measuring system **200** according to one of aspects 1 to 10, wherein the measuring system **200** includes one or several additional sensor heads, such that the same includes at least four sensor heads.

A twelfth aspect relates to a measuring system **200** according to aspect 11, wherein the calculation unit is configured to determine a regression line RG based on a point cloud defined by the first, the second, the third and a fourth measuring value.

A thirteenth aspect relates to a measuring system **200** according to one of aspects 1 to 12, wherein the measuring system **200** comprises an inclination sensor determining an absolute inclination and/or wherein the calculation unit is configured to determine, based on the absolute inclination, an absolute inclination of the component of the construction machine together with the angle α.

A fourteenth aspect relates to a measuring system **200** according to one of aspects 1 to 13, wherein averaging and/or temporal averaging of the measuring value takes place.

A fifteenth aspect relates to a measuring system **200** according to one of aspects 1 to 14, wherein the first sensor head **221** and the second sensor head **222** are spaced apart along the carrier **210**.

A sixteenth aspect relates to a measuring system **200** according to one of aspects 1 to 15, wherein the calculation unit is configured to consider based on a distance of the first sensor head and the second sensor head and/or the third sensor head during the calculation.

A seventeenth aspect relates to a layer thickness measuring system for a construction machine, wherein the layer thickness measuring system comprises a carrier **210** and a further carrier **215** connectable to a screed **10** of the construction machine such that the carrier **210** extends in front of the screed **10** and the further carrier **215** extends behind the screed **10**, the layer thickness measuring system comprising: first, second and third sensor heads that are connected to the carrier **210** and are configured to measure a first distance from the first sensor head to a ground or a reference to obtain a first measuring value, and to measure a second distance from the second sensor head to a ground or a reference to obtain a second measuring value, and to measure a third distance from the third sensor head to a ground or a reference to obtain a third measuring value; a further first, further second and further third sensor head that are connected to a further carrier **210** and are configured to measure a further first distance from the further first sensor head to a deposited layer to obtain a further first measuring value, and to measure a further second distance from the further second sensor head to the deposited layer to obtain a further second measuring value, and to measure a further third distance from the further third sensor head to the deposited layer to obtain a further third measuring value; a calculation unit configured to determine a regression line RG based on the first, second and third measuring values H**1**, H**2**, H**3**, and to determine a further regression line RG**2** based on the further first, further second and further third measuring value; wherein the calculation unit is configured to determine a layer thickness based on the position of the regression line RG relative to the further regression line RG**2**.

An eighteenth aspect relates to a layer thickness measuring system according to aspect 17, wherein the carrier **210** and the further carrier **215** run parallel or are oriented in the same direction or in a fixed relationship to one another; and/or wherein the regression line RG and the further regression line RG run in parallel or are aligned such that the regression line RG and the further regression line RG**2** run in parallel.

A nineteenth aspect relates to a layer thickness system according to aspect 17 or 18, wherein an offset of the regression line RG relative to the further regression line RG**2** corresponds to a layer thickness or allows conclusions on the layer thickness.

A twentieth aspect relates to a Construction machine, in particular a road construction machine, such as a road finishing machine or a road milling machine comprising a measuring system **200** or layer thickness measuring system according to one of aspects 17 to 19.

A twenty-first aspect relates to a method for determining a position of a component of a construction machine by using a measuring system **200**, wherein the measuring system **200** comprises a carrier **210** connectable to a component of the construction machine, comprises a first, a second and a third sensor head that are connected to the carrier **210** and configured to measure a first distance from the first sensor head to the ground to obtain a first measuring value H**1**, and to measure a second distance from the second sensor head to the ground to obtain a second measuring value H**2**, and to measure a third distance from the third sensor head to a ground or a reference to obtain a third measuring value H**3**, wherein the first, second and third sensor heads have a substantially parallel orientation, such that a scanning area extending in parallel or substantially in parallel is formed, comprising: determining a regression line RG together with a slope of the regression line RG relative to the ground or the reference based on the first, second and third measuring values H**1**, H**2**, H**3**; and determining an angle α describing the slope of the regression line RG and the position of the component of the construction machine relative to the ground, based on the slope.

A twenty-second aspect relates to a method according to aspect 21, wherein the measuring system comprises a further first, further second and further third sensor head that are connected to a further carrier **215** and are configured to measure a further first distance from the further first sensor head to the ground or to the reference to obtain a further first measuring value, and to measure a further second distance from the further second sensor head to the ground or the reference to obtain a further second measuring value, and to measure a further third distance from the further third sensor head to the ground or the reference to obtain a further third measuring value; the method comprising: determining a further regression line RG**2** together with a slope of the further regression line RG**2** relative to the ground or the reference based on the further first, further second and further third measuring values; and determining an angle α describing the slope of the further regression line RG**2** and the position of the component of the construction machine relative to the ground, based on the slope, determining a layer thickness based on the regression line RG and the further regression line RG**2**.

A twenty-third aspect relates to a method for determining a layer thickness by means of a layer thickness measuring system comprising a carrier **210** and further carrier **215** connectable to a screed **10** of the construction machine such that the carrier **210** extends in front of the screed **10** and the further carrier **215** extends behind the screed **10**, wherein the layer thickness measuring system further comprises first, second and third sensor heads that are connected to the carrier **210** and are configured to measure a first distance from the first sensor head to a ground or a reference to obtain a first measuring value, and to measure a second distance from the second sensor head to a ground or a reference to obtain a second measuring value; and to measure a third distance from the third sensor head to a ground or a reference to obtain a third measuring value; wherein the layer thickness measuring system comprises a further first, further second and further third sensor head that are connected to a further carrier **215** and are configured to measure a further first distance from the further first sensor head to a deposited layer to obtain a further first measuring value, and to measure a further second distance from the further second sensor head to the deposited layer to obtain a further second measuring value; and to measure a further third distance from the further third sensor head to the deposited layer to obtain a further third measuring value; comprising: determining a regression line RG based on the first, second and third measuring values H**1**, H**2**, H**3**; and determining a further regression line RG**2** based on the further first, further second and further third measuring value; determining a layer thickness based on the position of the regression line relative to the further regression line RG**2**.

A twenty-fourth aspect relates to a computer program having a program code for performing any of the above methods when the program runs on a measuring system of an inventive construction machine on an measuring system according to one of aspects 1 to 16 or a layer thickness measuring system according to one of aspects 17 to 19.

Although some aspects have been described in the context of a device, it is understood that these aspects also represent a description of the corresponding method so that a block or component of a device is also to be understood to be a corresponding method step or feature of a method step. Similarly, aspects described in connection with or as a method step also constitute a description of a corresponding block or detail or feature of a corresponding device. Some or all of the method steps may be performed by (or using) a hardware apparatus, such as a microprocessor, a programmable computer, or an electronic circuit. In some embodiments, some or more of the key method steps may be performed by such an apparatus.

Depending on particular implementation requirements, embodiments of the invention may be implemented in hardware or in software. The implementation may be performed using a digital storage medium, for example, a floppy disk, DVD, Blu-ray disc, CD, ROM, PROM, EPROM, EEPROM, or FLASH memory, a hard disk, or any other magnetic or optical storage medium on which electronically readable control signals are stored which can or do interact with a programmable computer system so as to perform the particular method. Therefore, the digital storage medium may be computer-readable.

Thus, some embodiments according to the invention include a data carrier having electronically readable control signals capable of interacting with a programmable computer system such that any of the methods described herein are performed.

Generally, embodiments of the present invention may be implemented as a computer program product having program code, the program code being operative to perform any of the methods when the computer program product runs on a computer.

For example, the program code may also be stored on a machine-readable medium.

Other embodiments include the computer program for performing any of the methods described herein, wherein the computer program is stored on a machine-readable medium.

In other words, an embodiment of the inventive method is thus a computer program having program code for performing any of the methods described herein when the computer program runs on a computer.

Thus, another embodiment of the inventive methods is a data carrier (or digital storage medium or computer-readable medium) on which is recorded the computer program for performing any of the methods described herein. The data carrier, digital storage medium, or computer-readable medium is typically tangible and/or non-transitory or non-transient.

Thus, another embodiment of the inventive method is a data stream or sequence of signals which represents the computer program for performing any of the methods described herein. For example, the data stream or sequence of signals may be configured to be transferred over a data communication link, such as over the Internet.

Another embodiment includes a processing device, such as a computer or programmable logic device, configured or adapted to perform any of the methods described herein.

Another embodiment includes a computer having installed thereon the computer program for performing any of the methods described herein.

Another embodiment according to the invention includes a device or system configured to transmit a computer program for performing at least one of the methods described herein to a receiver. The transmission may be, for example, electronic or optical. The receiver may be, for example, a computer, mobile device, storage device, or similar device. The device or system may include, for example, a file server for transmitting the computer program to the receiver.

In some embodiments, a programmable logic device (for example, a field programmable gate array, FPGA) may be used to perform some or all of the functionalities of the methods described herein. In some embodiments, a field programmable gate array may interact with a microprocessor to perform any of the methods described herein. Generally, in some embodiments, the methods are performed on the part of any hardware device. This may be general-purpose hardware, such as a computer processor (CPU), or hardware specific to the method, such as an ASIC.

The devices described herein may be implemented using, for example, a hardware apparatus, or using a computer, or using a combination of a hardware apparatus and a computer.

The devices described herein, or any components of the devices described herein, may be implemented at least in part in hardware and/or in software (computer program).

For example, the methods described herein may be implemented using a hardware apparatus, or using a computer, or using a combination of a hardware apparatus and a computer.

The methods described herein, or any components of the methods described herein, may be performed at least partly by hardware and/or by software.

While this invention has been described in terms of several advantageous embodiments, there are alterations, permutations, and equivalents, which fall within the scope of this invention. It should also be noted that there are many alternative ways of implementing the methods and compositions of the present invention. It is therefore intended that the following appended claims be interpreted as including all such alterations, permutations, and equivalents as fall within the true spirit and scope of the present invention.

The invention claimed is:

**1**. A construction machine comprising a measuring system, wherein the measuring system comprises a carrier connectable to the construction machine, such that the carrier extends along a longitudinal axis of the construction machine, especially laterally to the same, comprising:

at least a first portion of the carrier; wherein the first portion comprises a plurality of sensor heads attached to or integrated with the first portion for non-contact measurement against a ground or reference as well as first and second end faces, and wherein the first portion comprises a second connecting element at a second end face, the second connecting element being connectable to a first connecting element such that both a mechanical and electrical connection is formed.

**2**. The construction machine according to claim **1** comprising a second portion of the carrier, wherein the second portion comprises a plurality of attached or integrated sensor heads, wherein the second portion comprises the first connecting element at a first end face, wherein the second connecting element of the first portion is connectable to the first connecting element of the second portion such that both a mechanical and electrical connection is formed.

**3**. The construction machine according to claim **1**, wherein the measuring system comprises an attachment element connectable to the construction machine or a component of the construction machine and comprising a first and/or a second connecting element; or

wherein the measuring system comprises an attachment element connectable to the construction machine or a component of the construction machine and comprising a first and/or a second connecting element, such that the first portion is connectable to the construction machine or the component of the construction machine.

**4**. The construction machine according to claim **1**, wherein the first and/or the second portion comprises sensor heads aligned on a longitudinal side perpendicular to the longitudinal axis of the first and the second portion; or

wherein the first and/or the second portion comprises sensor heads on a longitudinal side that are directed to the ground or the reference.

**5**. The construction machine according to claim **1**, wherein the first and/or the second portion each comprise a plurality of attached or integrated sensor heads and/or at least three attached or integrated sensor heads.

**6**. The construction machine according to claim **1**, wherein the sensor heads differ with respect to their measurement principles.

**7**. The construction machine according to claim **1**, wherein the measuring system comprises a reflector or an inclined reflector at the first and/or a second end face.

**8**. The construction machine according to claim **1**, wherein the electrical connection comprises a contact connection, inductive or non-contact connection.

**9**. The construction machine according to claim **1**, wherein the measuring system comprises at least one third further sensor head per first and/or second portion or per carrier that is aligned parallel to the longitudinal axis and/or that is arranged on the first and/or second end face; and/or wherein the third further sensor is configured to determine a distance to an object performing a relative movement with respect to the construction machine or a component of the construction machine.

**10**. The construction machine according to claim **1**, wherein measurements of the sensor heads substantially take place simultaneously.

**11**. The construction machine according to claim **1**, wherein the first portion comprises a display or an LED display,

wherein the display and/or LED display is configured to display a connecting state between the first and second portions or to display information, e.g., with respect to a deviation of the measuring system or a control system connected to the measuring system.

**12**. The construction machine according to claim **1**, wherein the measuring system comprises a sensor, a GNSS sensor, an inclination sensor, an infrared sensor, a temperature sensor, a position sensor or a further sensor.

**13**. The construction machine according to claim **1**, wherein the measuring system comprises a third portion comprising a first connecting element at a first end face, wherein the first connecting element is connectable to a second connecting element, such that both a mechanical and electrical connection is formed.

**14**. The construction machine according to claim **1** comprising a road construction machine, a road finishing machine or a road milling machine.

**15**. The construction machine according to claim **1**, wherein a second portion comprises a second connecting element at a second end face and/or the first portion comprises a first connecting element at a first end face.

**16**. The construction machine according to claim **15**, wherein the first and/or the second connecting elements comprises an electrical coupler extending substantially along the longitudinal direction of the respective portion.

**17**. The construction machine according to claim **1**, wherein the first and/or the second connecting element comprises a hook, such that the first connecting element and the second connecting element can be engaged by a rotational movement.

**18**. The construction machine according to claim **17**, wherein the hook of the first or second connecting element or the hooks of the first and second connecting elements comprise an engagement surface that is opened substantially perpendicular to the longitudinal direction of the respective portion; and/or

wherein the rotational movement is defined by an end stop that needs the first and second end faces to be in contact.

**19**. The construction machine according to claim **1**, wherein the first and/or second connecting elements comprise a profile comprising an end stop extending substantially perpendicular to the longitudinal direction of the respective portion, such that the two connecting elements are connectable by a translational movement substantially perpendicular to the longitudinal direction of the respective portion.

**20**. The construction machine according to claim **19**, wherein the first and/or second connecting element each comprise an electrical coupler extending substantially perpendicular to the longitudinal direction of the respective portion.

**21**. The construction machine according to claim **1**, wherein the first connecting element comprises a sleeve extending substantially in the longitudinal direction of the

respective portion and wherein the second connecting elements are connectable by inserting the second connecting element into the sleeve.

**22**. The construction machine according to claim **21**, wherein the first and/or the second connecting element comprise a respective electrical coupler extending substantially along the longitudinal direction of the respective portion.

**23**. The construction machine according to claim **21**, wherein the first connecting element comprises a lever mechanism and/or a lever mechanism with an eccentric, for translationally fixing the first connecting element to the second connecting element.

**24**. The construction machine according to claim **1**, wherein in the respective first the sensors heads are spaced apart from each other.

**25**. The construction machine according to claim **24**, wherein the sensor heads are equally distributed in the respective first and/or second portion or across the carrier.

**26**. The construction machine according to claim **1**, wherein the measuring system comprises at least one first further sensor head per first and/or second portion or per carrier that is aligned parallel to the longitudinal axis and/or arranged at the first and/or second end face; and/or wherein the first further sensor head is configured to perform a reference measurement.

**27**. The construction machine according to claim **26**, wherein the measuring system comprises a second sensor head per first and/or second portion that is arranged along the longitudinal axis of the respective first and/or second portion or the carrier and that is on the opposite end face of the first further sensor head.

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