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(54) **Titre** : DISPOSITIF ET PROCEDE DE CONTROLE NON DESTRUCTIF D'OBJETS PAR ULTRASONS ET UTILISATION DE CAPTEURS MULTI-ELEMENTS MATRICIELS
(54) **Title**: DEVICE AND METHOD FOR THE NON-DESTRUCTIVE TESTING OF OBJECTS USING ULTRASOUND AND THE USE OF MATRIX-PHASED ARRAY PROBES

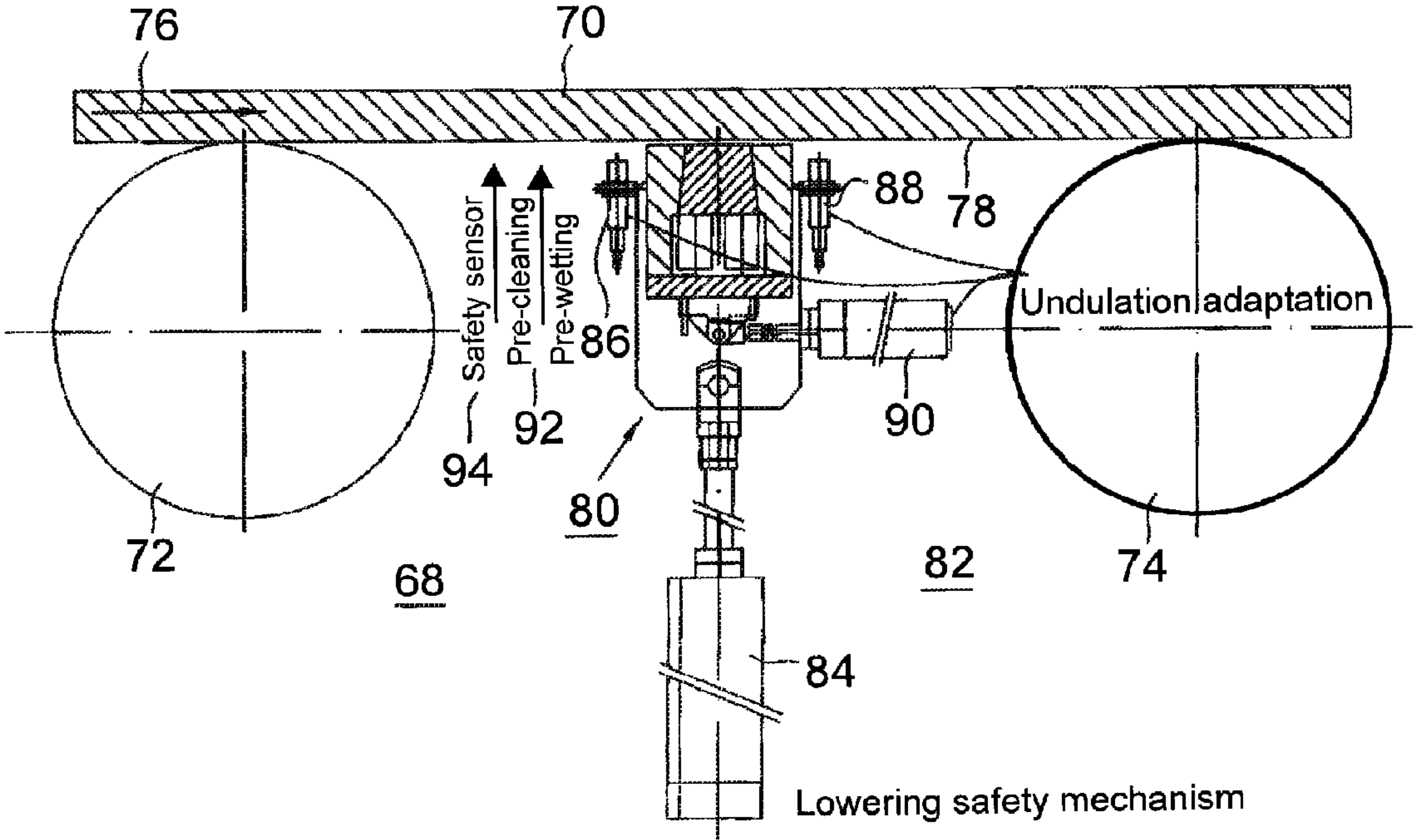

FIG. 5

(57) **Abrégé/Abstract**:
The invention relates to a device (68) and a method for the non-destructive testing of planar objects (70) such as thick or thin metal sheets using ultrasound in different focal zones, said device comprising one or more independently controllable probes (PK1-PKn), and to the use of matrix phased array probes. To achieve uniform sensitivity over a wide thickness range, the probes (PK1-PKn) are designed as 2-dimensional phased array probes (PK2-PKn) and are located in rows offset in relation to one another. The sum of the number and length of the individual probes (PK1, PKn) corresponds to the width of the material to be tested.

DEVICE AND METHOD FOR THE NON-DESTRUCTIVE TESTING OF OBJECTS USING ULTRASOUND AND THE USE OF MATRIX PHASED ARRAY PROBES

ABSTRACT

The invention relates to a device (68) and a method for the non-destructive testing of planar objects (70) such as thick or thin metal sheets using ultrasound in different focal zones, said device comprising one or more independently controllable probes (PK1-PKn), and to the use of matrix phased array probes. To achieve uniform sensitivity over a wide thickness range, the probes (PK1-PKn) are designed as 2-dimensional phased array probes (PK2-PKn) and are located in rows offset in relation to one another. The sum of the number and length of the individual probes (PK1, PKn) corresponds to the width of the material to be tested.

Device for Non-destructive testing of smell through Ultrasound

The invention refers to a device as per the preamble of claim 1.

' A device of the input-named type is described in DE-A-34 42 751. The device shows probes adjustable on the sheet, which are provided crosswise for direction of flow sequence wise and behind each other with overlapping in direction of flow in many arrays and respectively shows a sender and a receiver. Every probe is provided with a device for applying water film between every probe and sheet. The probe within an array are arranged in a movable and/or adjustable way crosswise for direction of flow under setting at an equal distance from one probe to another.

In US-B-7,263,888, a two-dimensional phased array for volumetric ultra sound testing and a process for use of Phased Arrays is described. The Phased Array consists of a variety of ultra sound converters, which are arranged in a perpendicular sample.
The two-dimensional array enables electronic setting of focal point features and size of aperture/covers both in sidewise-and height directions, so that uniform and/or specific sound field characteristics can be reached at any or all positions in the tested components.

A modulation can be used on each of the ultra sound elements, in order to form a scanning beam and to at least scan an area of testing material with the scanning beam.

body from the saved ultrasound signals without the need for additional ultrasound measurements. On the assumption that all transmitters transmit simultaneously, the number i of ultrasound transmitters and the specific composition of the transmitter group, in particular its arrangement on the test body surface, also determine the overall radiation characteristics (aperture) of the transmitter group and furthermore the sensitivity and the resolution of the measurements. The activation of all ultrasound transducers of an array for transmission of a complete wave front is not disclosed in this publication.

DE-C-34 42 751 relates to a test system operating with ultrasound for metal sheets of varying width conveyed lying flat on a roller conveyor. The facility comprises test heads (probes) adjustable towards the sheet and provided in a plurality of rows transversely to the conveying direction and arranged one behind the other with an overlap of their test tracks, and each having a transmitter and a receiver. Furthermore, a device is provided for applying a water film between each probe and the metal sheet. The probes within each row are arranged movably or adjustably transversely to the conveying direction for setting an equal spacing between the probes and for continuing the overlapping test tracks. Furthermore, a device for measuring the metal sheet width is provided. The probes of one row are set in accordance with the measured sheet width between the longitudinal edges of the metal sheet such that two probes of this row are adjusted towards the sheet adjacent to the edge.

US-B-4,989,143 describes a method for representing a coherent energy beam and in particular a new method for improved adaptive formation of a coherent beam using iterative phase conjugation in order to counteract the effects of inhomogeneous wave propagation.

The article by SUNG-JIN SONK et al. "Development of an Ultrasonic Phased Array System For Nondestructive Tests of Nuclear Power Plant Components" , in "Nuclear Engineering and Design 214" (2002); p. 151-161, describes a phased array ultrasonic inspection system which arose from the modification of a medical ultrasound imaging system that had 64 individual transceiver channels. The document describes the time-lagged operation of ultrasound transmitting elements.

AT-B-307 088 describes a device for continuous strip testing comprising at least one test probe. A frame receiving the test probe and adjacent to the strip is suspended in a support oscillating about a horizontal axis extending in the strip running direction. The support is mounted in a base frame oscillating about a horizontal axis extending transversely to the strip running direction.

DE-U-72 40 684 describes a probe for systems for continuous ultrasonic testing of rolled strip. The probe comprises a probe housing and at least one ultrasonic probe arranged therein, where the probe housing is designed as a coupling chamber through which can flow a coupling liquid and is movably connected to a test carriage. A pre-wetting chamber is provided in front of the coupling chamber. Guide rollers are fitted underneath the probe housing and a wiper is provided behind the coupling chamber.

A method and a device for ultrasonic inspection of different zones of a billet are described in US-A-5,533,401. Here a plurality of ultrasonic transducers with focal zones of varying depth is positioned for examining a cylindrical titanium billet through its thickness. The focal zones partially overlap the adjacent focus zones, thus ensuring complete examination through the thickness of the entire billet. The reflected signals from the transducer receivers are processed into digital form to generate an image of the billet.

A method of this type is however expensive, since every probe has to be individually adjusted and adaptation to surface irregularities is difficult.

A method for non-destructive inspection of a test body using ultrasound is described in DE-A-10 2005 051 781. In this method, ultrasonic waves are injected into the test body with one or with a plurality of ultrasonic transducers, and ultrasonic waves reflected inside the test body are received by a plurality of ultrasonic transducers and converted into ultrasonic signals. An ultrasonic transducer is provided on one surface of the test body and activated such that the ultrasonic waves coupled into the test body propagate largely uniformly spatially distributed inside the test body.

Then the ultrasonic waves reflected inside the test body are received with a plurality of ultrasonic transducers provided on the surface and ultrasonic time signals are generated containing time-resolved amplitude information.

The ultrasonic time signals are saved. Then a three-dimensional volumetric image, a sector image in the form of a two-dimensional ultrasonic sectional image through the test body or an A-image in the form of a one-dimensional time-resolved and locally resolved ultrasonic signal along a given irradiation angle is reconstructed, exclusively using at least a part of the ultrasonic time signals.

A further method is described in EP-B-1 649 301. With this method, a complete wavefront is transmitted to at least one section of the object to be tested using a plurality of independent transmission elements. A wave reflected from the surface of the object is then received by a plurality of independent receiver elements. The signals received by the receiver elements are then digitized in digitizing steps and further processed. Dynamic depth focusing or aperture adaptation is not touched upon in EP-B-1 649 301.

In the prior art, dual contact probes with water film coupling and plastic interface are used. Each of up to 100 probes must be individually positioned, requiring high expenditure on control technology. In addition, the probes must be routinely tested for suitable ultrasonic coupling quality.

Since each probe can only operate when it is completely covered by the sheet to be tested, sheet edges have a non-examined minimum zone which is as wide as the width of the individual probe. This width is currently in the region of 50 mm.

Proceeding from that basis, the object underlying the invention is to develop a device for testing of planar material such as thick or thin metal sheet such that a uniform sensitivity is achieved over a wide thickness range. Furthermore, the device should be improved to the extent that no moving parts are required and that it is suitable for testing the planar materials close to their edges without any additional equipment. A new and inventive used of a phased array is proposed.

To solve the problem, it is also provided that the probes are designed as two-dimensional phased array probes and are arranged in a row next to one another and without any gaps, the sum of the number and the length of the individual probes corresponding to a width of the material to be tested. The two-dimensional phased array probe or the probe strip formed by lining up probes without gaps is used to improve signal quality and resolution, employing dynamic depth focusing and dynamic aperture adaptation. The mechanical design of the probe and probe holder is simplified by an ultrasound coupling using segment immersion technology.

and m ultra sound time signals are generated, in which time-resolved aplitude information is included.

The m ultrasound signals are saved. after this a 3dimensional volume image, a sectorial diagram in the form of a 2dimensional ultrasound image through the test object or an A-image in the form of a 1dimensional ultrasound signal that can resolve in terms of space and time along a definable irradiation angle is reconstructed, exclusively by using at least a part of the m ultrasound signals.

Another method is described in the EPB1 649 301. In this method, a complete wave front is made to impinge on at least one section of the object, which is to be tested, using a number of independent transmission elements. After this, a wave that is reflected by the structure of the object is received with the help of a large number of mutually independent reception elements. The signals that are received by the reception elements are digitalized in digitalization steps and processed further. EPB1 649 301 does not speak of any dynamic depth focusing or an aperture adaption.

As per the state of the art, dual contact probes with water film coupling and synthetic interface are used. Each of the probes, which could number up to 100 must be programmed individually, which requires a high effort in terms of control technology. In addition to this, the probes should be checked as a matter of routine with respect to a suitable ultrasound coupling quality.

Since every probe can work only if it is covered completely by the board, which is to be tested, the edges of the boards have a minimum zone that cannot be checked, which is as wide as the individual probe. This width is currently in the range of 50 mm.

The US-B-5,490,512 refers to a transducer array, comprising a large number of transducer elements, which are arranged in a 2 dimensional array and which have transverse and longitudinal extensions. Further, it envisages a device for generating and supplying electrical excitation signals for the transducer elements. To measure the signals that are received by the transducer element, these are connected together in groups.

Based on this, it is the task of the present invention to provide a device for testing flat materials such as thin or thick sheets in such a way that a uniform sensitivity is ensured over a wide range of thicknesses. Further, the device is to be improved in that no moving parts are necessary and that this is suitable for testing flat materials without necessitating the use of any additional equipment, even close to the edges. A new and innovative usage of a Phased Array is suggested.

The task is resolved in accordance with the invention by the features of the Claim 1.

The mechanical design of probe and test object holder is simplified through an ultrasound coupling with the segment immersion technique.

By using matrix array scanner heads, which can be programmed individually to suit the individual thickness zones, which overcomes the poor resolution of conventional immersion technique heads.

The segment immersion technique, in comparison with the usual water splitting technology, permits a much simpler mechanical solution and does not require any additional scanning heads that follow the edges, to permit a testing / inspection close to the edges of the plates.

Compared to the state of the art, a strong mechanical simplification, and a higher resolution of problem (noise) areas are achieved. In addition, the local segment immersion technique is less sensitive to unevennesses in the surface of the material that is to be tested.

The device is suitable for testing thin or thick sheets in the thickness range of 4 to 400 mm.

and produces the time-lag as the result, while the parameters are set depending on the application.

The problem with the prior art is that the number of applicable time-lag sets for the arrays is in the final analysis limited by the capacity of the hardware and by the processing times for data transfer. With a larger number of elements and additional zones to be tested, the need for storage capacity increases.

In addition, the zone requires for varying time-lag laws a special treatment so that no discontinuity occurs within the images produced by the ultrasonic device. To overcome this, modern instruments compute the time-lag on the basis of a distance algorithm for very small zones or for every scanned point. This distance algorithm is only suitable for sufficiently homogeneous media without severe discontinuities, which are usual in non-destructive testing. When computing the distance, fixed relationships were already used, however with a significantly higher number of parameters being needed.

In accordance with the idea inventive per se as described here, this problem is solved by the use of functional descriptions for the time-lag-generating circuits. The time-lags generally used for ultrasonic problems can be defined by a static and differential function between the first element of the array and the last element of the array. The functional descriptions permit the generation of a curve for the time-lags of all elements, the time-lag value being a function of the array number. For one-dimensional arrays, this is a function with one variable, for 2-dimensional arrays it is a function of at least two variables and so on.

The functional description furthermore contains a limited number of parameters. These parameters change for each of the selected time-lag zones and must be individually adapted.

A one-dimensional virtual probe with 32 transmitter/receiver elements requires for example 64 time-lag values for a second zone. If a functional description in the form of a cubic Bezier function is applied, the number of required parameters for a second zone can be reduced to eight values: four values for transmission and four for receiving.

To smooth the transition between the time-lag zones, linear interpolations can be made between the functionally described values of two zones depending on the time difference between the currently considered scanning and two reference time positions. The same method can be used for apodization or overlap weighting. In this case the result of the functional description is the amplitude for the element of the array. The argument is the element itself, and the parameters are transmitted within the ultrasonic system or computed in advance for higher-dimensional cases and set down in a table to be transferred.

Thanks to the solution in accordance with the invention, the advantages obtained in comparison with the prior art are that considerably fewer parameters have to be transferred, so that less storage capacity is needed. The number of cycles too can be increased, and an adaptation to highly complex geometrical situations is likewise possible.

In summary, the method in accordance with the invention is characterized in that parametrizable functions are used for the time-lag zones instead of fixed formulas or time-lag sets.

Further details, advantages and features of the invention can be gathered not only from the claims and in the features to be found therein, singly and/or in combination, but also from the description of preferred embodiments to be found in the description of the drawing.

The drawing shows in:

Fig. 1	a block diagram of a control unit for phased array probes,
Figs. 2a) - d)	a schematic representation of a plan view onto a probe in the transmitting and receiving state,
Fig. 3	a schematic representation of a probe with different system testing cycles,
Figs. 4a), b)	a schematic representation of a probe above a non-ideal irradiation geometry and an image of a parallel B-scan,
Fig. 5	a schematic representation of a probe arrangement in local immersion for testing a planar material from below,
Fig. 6	a plan view onto the probe array in accordance with Fig. 5,
Figs. 7a) - e)	a schematic representation of a plan view onto a probe in the transmitting and receiving state,
Fig. 8	a schematic representation of a probe with different testing cycles,
Figs. 9a), b)	a side view of a probe strip and a plan view onto a probe strip,
Fig. 10	a front view of a second embodiment of a probe array in the form of a probe bar,

Fig. 11	a side view of the probe bar in accordance with Fig. 7 and
Fig. 12	a side view of a further embodiment of a probe bar.

Fig. 1 shows a block diagram of a control unit preferably comprising N = 128 channels. For each of the up to N = 128 ultrasonic transducer elements 10, a pulser 12 is provided which is controllable via an input 14. A time-lag of for example 5 ns can be switched on or off using a further input 16. The signals received from the ultrasonic transducer elements 10 are recorded in two channels, where each channel comprises an operational amplifier 18, 20, a low-pass filter 22, 24 and an A/D converter 26, 28. The operational amplifiers 18, 20 of the individual channels have different amplifications. The A/D converters are connected to their digital output, i.e. to a programmable integrated circuit 30. The digital output of the A/D converter 26, 28 is connected to an input of a deserial module 32, 34. One output of the deserial module is connected to an input of an offset correction module 36, 38 whose outputs are connected to a multiplexer 40. The multiplexer 40 is connected on the output side to an external memory module 42 such as a RAM and to a processing unit 44.

In the processing unit 44, channel selection and also dynamic depth focusing and dynamic aperture adaptation take place. The time-lag provided is for example 5 ns. One output of the external memory module 42 is connected to the aperture processing unit 44. Furthermore, an internal memory module 46 is provided which is likewise connected to the aperture processing unit 44.

One output of the unit 44 having a summation module is connected to a processor 48 in which the amplification, filtering and time control amplification of real-time HF amplitude scaling is performed in a digital manner. At the output of the processor 48, a signal is transmitted which is applied at a first input 52.1 of a multiplexer 50. A header, a sequence number or a control word can be applied at a second input 52.2 of the multiplexer. The respective input can be selected using the third input 52.3. At the output of the multiplexer 50, for example, a 17 bit signal is applied which is made available for further processing via a fast serial link 54. A further component of the circuit is an input module 56 for entering signals at various units of the circuit 30.

The method in accordance with the invention is performed as follows. First, a complete wave front is transmitted via the pulse generators 12 by simultaneous (phase-rigid) control of all ultrasonic transducer elements vertically onto at least one section to be tested of an object. A wave reflected by the structure of the object is then received by a plurality of independent ultrasonic transducer elements 10. The signals received from the ultrasonic transducer elements 10 are digitized in a digital signal processing unit 30 in digitizing steps, electronically processed and saved in the memory module 44 or 46.

There is a continuous change here in time-lag values and/or in the number of ultrasonic transducer elements of a virtual probe for each digitization step on-the-fly, since for every digitization step on-the-fly the time-lag values and/or the number of ultrasonic transducer elements has to be adapted. The time-lag values are computed from a saved start time-lag (focal law for surface position) to an end time-lag (focal law for a rear wall position) by means of a distance function such as l/R where R = radius. The time-lag values can be saved in a reference table, in particular in the case of complex coherence. In the present case, the time-lag values are plotted in the form of a curve.

The aperture adaptation is performed by linear change of the number of receiving elements, preferably in the summation module 44.

A major change in the time-lag values and/or aperture adaptation is usually triggered by the "time-of-flight" position (runtime position) of the surface/interface echo. In the summation module 44, summation is conducted of various focused transmitter shots into one signal by the use of a digital TGC function. Additionally, the time-lag values can be defined by functional dependences by means of, for example, a Bezier function, polynomial or other type of function, where the function indices of the ultrasonic transducer elements are used as the argument and the time-lag values are produced as the results, while parameters are set depending on the application.

Figs. 2a to 2d show in purely schematic form plan views of a probe 62 in the form of a matrix-phased array probe. The latter comprises a plurality of individual ultrasonic transducer elements 10 which are individually controllable.

As already set forth, all ultrasonic transducer elements 10 are operated simultaneously for transmission, as shown in Fig. 2a.

Following the principle of runtime-controlled focusing (dynamic depth focusing) and runtime-controlled receiving aperture (dynamic aperture), for focus zones of interest in Figs.

2b to 2d one element as in Fig. 2b, five elements as in Fig. 2c or nine elements as in Fig. 2d are switched to receive for focusing zones of differing depths.

Each probe 62 can for example have 128 ultrasonic transducer elements 10. Probes with 5 x 25 = 125 elements are preferably used, as a result of which an active surface can be obtained for example in the region of 35 mm x 175 mm.

To cover metal sheet widths in the range from 1000 mm to 5300 mm, about 36 probes 62 are required.

A system probe 64 with 24 elements is shown in Fig. 3, where to match the system test cycle Tl... Tn nine ultrasonic transducer elements 10 are switched on in each case step by step and switched to receive.

With the method in accordance with the invention, a higher coupling reliability is obtained for rough surfaces compared with the conventional contact technology. Furthermore, all probes can be arranged without gaps over the entire sheet width, with a width pixelization of for example 6 mm. Edge and top/bottom testing are integrated into the concept. Also, higher-value reconstruction methods can be incorporated by early digitization of all test data. Furthermore, the parallel-B scan principle is made possible, i.e. transmitting and receiving of all ultrasonic transducer elements simultaneously.

The parallel-B scan method permits robust testing also for non-ideal irradiation geometries 66, as shown in Fig. 4a. The non-ideal irradiation geometry 66 can for example have a curved front wall and/or a curved rear wall, as shown in Fig. 4b.

A first embodiment of a test array 68 is shown in Fig. 5 in a side view. An object 70 to be tested in the form of a planar material such as a thin or thick metal sheet is mounted on transport rollers 72, 74 and is transportable in the direction of the arrow 76. On an underside 78 of the material 70 to be tested, a probe array 80 is provided by which the individual probes PKl - PKn are coupled by a segment technology to the material 70 to be tested. The probe array 80 is designed as a water chamber open to the top which equalizes via a continuous water supply the water loss incurred in the gap to the object 70 to be tested, and hence ensures a flawless coupling of the ultrasound. The probe array 80 is preferably sealed with a lip seal from the underside 78 of the material to be tested in order to reduce the water loss.

Alternatively, leading and trailing gliding shoes can be provided in the movement direction 76 of the test material 70 to protect the probe array 80 from damage when the test material is excessively uneven. The probe array 80 can be lowered using a control element 84 and dynamically readjusted using further control elements 86, 88, 90 for adapting the undulation. Mounted in front of the probe array 80 are a pre-cleaning unit or pre-wetting unit 92 and a safety sensor 94 ensuring shutdown in the event of a fault.

Fig. 6 shows a plan view of the probe array 80, where individual probes PKl- PK6 or PKn are arranged inside a water pool 96. The water pool is sealed by means of a preferably all-round sealing element 98 such as a lip seal from the underside 78 of the material 70 to be tested. Here the probes PKl, PK3, PK5 are arranged along a first longitudinal axis 98 at a distance from one another, where along a second axis 100 running parallel to the first axis the probes PK2, PK4, PK6 are arranged such that they run offset to the probes PKl, PK3, PK5. In this way, a total width B of the area to be tested is covered by ultrasonic transducer elements. Every single one of the ultrasonic probes Pk i is connected here to one of the ultrasonic control units i (in accordance with Fig. 1). In this way, the test can be conducted simultaneously and parallel with every single probe and hence the testing capacity can be increased. Inside a probe, focused transmission takes place depending on test requirements with a group of preferably 5 x 5 elements of the matrix probe onto the rear wall of the test specimen. The identical receiving group is then evaluated, depending on the depth zone, with the described dynamic aperture adaptation by selecting the appropriate receiving elements and/or dynamic depth focusing by the adaptation of the time-lags. To cover the entire probe surface, the described group in the next ultrasonic shot is then moved one matrix element further in the probe longitudinal direction until the entire probe aperture has been scanned. Alternatively, it is also possible in a further test mode to control the transmission-side aperture (e.g. only the middle element or a 3 x 3 element group) with appropriate focusing and to evaluate the saved and received ultrasonic signal from the various transmission shots combined corresponding to the depth zone again with aperture and focusing adaptation. A further test mode comprises a transmission shot of the entire aperture of the probe (e.g. 5 x 25 matrix elements) with linear focusing onto the rear wall of the test specimen and with evaluation of the saved reception signals in accordance with the method described at the outset of indexing a 5 x 5 element group.

The probe array 80 is able to perform a 100% surface test of untrimmed rolled plates in the production flow. It is possible here to treat / test metal sheets with lengths up to 30000 mm, widths of 1000 to 5300 mm and thicknesses in the range from 4 mm to 300 mm.

The test can be done in one pass, in particular surface zone and edge zone testing, where the latter can be done longitudinally and transversely. The test speed is about 0.5 m/sec for 1000 ultrasonic shots/sec. The coupling is done - as set forth above - via water gaps with a circulating water supply.

The method in accordance with the invention permits reliable detection depending on the material thickness, where with a thickness of 8 mm to 240 mm ERG Ø 3 can be reliably detected up to a distance of 3 mm from the surfaces, and in a thickness range of 240 mm to 400 mm ERG Ø 5 up to a distance of 5 mm from the surfaces.

Overall, a modular structure is aimed at for increasing functional reliability, availability and maintenance-friendliness.

The method can be verified for example under the following conditions. Test method: pulse echo method with a water distance of 80 mm

Test body 1:

Material: carbon steel
Dimensions: length = 200 mm, width = 100 mm, thickness: 280 mm
Test defects: flat saddle holes, diameter 3 or 5 mm
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Test body 2:

Material: carbon steel
Dimensions: length = 100 mm, width = 100 mm, thickness: 20 mm
Test defects: blind holes, diameter 3 or 5 mm

Transducer (probe 1):
Type: 2D-face array transducer (18 elements)
Frequency: 4 MHz
Element size: 7 x 7 mm^2

Transducer (probe 2):
Type: 2D-face array transducer (24 elements)
Frequency: 5 MHz

Element size: 6 x 6 mm^2

The diagram of the matrix probe corresponds to that shown in Fig. 3.

A further diagram of a matrix probe is shown in Fig. 7. In accordance with Fig. 7a, the probe PK comprises 5 x 5 = 25 individual transmitting/receiving elements 10. The principle of runtime-controlled focusing (dynamic depth focusing) or runtime-controlled receiving aperture (dynamic aperture) can be seen in Figs. 7b) to 7d). Corresponding to the evaluation of the number of received ultrasonic signals of a probe PK, various zones (zone 1, zone 2, zone 3) of a test object can be tested, as shown purely schematically in Fig. 7 e).

Fig. 8 shows as an example lining up without gaps of individual probes PKl ... PKn to form a system probe APK or a probe strip PKL, which in turn results from lining up without gaps of system probes APK.

After transmission of the wave front by all probes PKl ... PKn, all ultrasonic receivers 10 of the probes PKl ... PKn are switched to receive, so that the incoming ultrasonic signals can be digitized in digitization steps and saved. Due to the timing of digitization, where the signals are digitized at any time, the signals receive depth information that can be evaluated. In a first test cycle Tl, the 25 individual signals of each probe PKl ... PKn are evaluated "on-the-fly", i.e. while the signals are still being received. In the further test cycles T2 ... T5, already saved ultrasonic signals are evaluated by further cycling in a "virtual probe", taking into consideration a continuous change in the time-lag values and/or in the number of receiving elements for each digitization step. Due to the digitization of the signals received by the receiving elements in digitization steps, every saved value also obtains depth information which can be evaluated. In the embodiment shown with probes PK with 25 transmitting/receiving elements, an evaluation can thus be made within 5 test cycles.

A single probe PKl ... PKn here comprises for example 5 x 5 = 25 individual transmitting/receiving elements 10 each with dimensions for example of 6 x 6 mm. The dimensions for a probe housing PKG shown in Fig. 9a are thus in the region of about 35 mm x 34.8 mm with 25 transmitting/receiving elements. A probe strip PKL is shown in Fig. 9b.

With a sheet width of, for example max. 5350 mm and an assumed probe housing width with 25 transmitting/receiving elements of 35 mm, the result is a required number of probes for covering the sheet width of 5350/35 = 153.

Assuming that 125 channels are available for each control unit SE, the result is a probe number of 5 per electronic unit. For a required probe number of 153, 31 electronic units are necessary.

Using 31 electronic units which can each process 5 probes, the result is a maximum probe number of 155, hence permitting coverage of a width of 155 x 35 mm = 5425 mm. This corresponds to an overlap of 75 mm in the case of a sheet width of 5350 mm.

Fig. 10 shows a front view of a second embodiment of a probe array 102 in the form of a probe bar. With this array, the probes PKl ... PKn in accordance with Fig. 9 are lined up without gaps as a probe strip PKL in order to permit complete testing of a planar material such as a metal sheet 104.

A side view of a first embodiment of the probe bar 102 is shown in Fig. 11. The probe bar 102 is arranged on a stationary or mobile support 106 not shown in further detail. Beams 108, 110 designed as a water supply are provided on this support. The beams 108, 110 are provided with a lifting device 112 using which the probe bar 102 can be advanced to the sheet 104 being tested. The lifting device can be of pneumatic design and have a stroke of around 20 mm in the extended state. The lifting device 112 comprises a height-adjustable platform 114 underneath which are arranged channels 116, 118 for the air supply.

In a preferred embodiment, the probe bar 102 is designed with an angle adjustment device 120 comprising an arc-shaped trough 122, swivellably mounted on rollers 124, 126 and settable using an adjusting mechanism 128. The angle can be set in the range from +/- 5°.

The trough is provided with longitudinally running beams 130, 132 by which the probe strip 134 is dependably supported. For the alignment of the probe strip 134, in particular during initial assembly, adjusting elements 136, 138 are provided which rest on an upper side of the beams 130, 132. At the side of the probe strip 134, collecting channels 140, 142 are arranged for coupling water which flows off or is wiped off. Above the probe strip, a slot 144 for water coupling to the material for testing is provided and limited at the side by rubber facings 146, 158 contacting an underside of the material to be tested.

Fig. 12 shows a further embodiment of a probe bar 150 in a side view substantially corresponding to the embodiment according to Fig. 11, so that identical elements are identified with the same reference numbers.

In this embodiment, the probe strip 134 opens into a test trough 152 limited at the side by wiping and sealing lips 154, 156. Parallel to the test trough, a pre-wetting channel 158 is provided opposite the sheet running direction and is used to pre-wet the material to be tested. The channel is limited at the side by a wiping and sealing lip 160 and by the wiping and sealing lip 154.

In the sheet running direction, a collecting channel 162 receiving the water exiting from the test trough 152 runs parallel to the latter. The collecting channel is limited at the side by a wiping and sealing lip 164 and by the wiping and sealing lip 156.

Patent claims

Device for non-destructive testing of sheets with ultrasound

1. Device (68) for the non-destructive testing of sheets (70) that are transported on transportation rollers (72, 74), such as thick or thin sheets, using ultrasound – consisting of one or more probes (PK1 PKn) that can be controlled separately, and which are arranged on the sheet (70), without gaps in a row that runs transverse with respect to the direction of transportation (76) or which are arranged in rows in a direction that runs transversely with respect to the direction of transportation (76) and in two rows, in the direction of transportation, with overlap, wherein one width B of the sheet (70) is covered by the probes (PK1 PKn), characterized in that the probes (PK1 PKn) are designed as 2dimensional matrix array probes (PK1 PKn), comprising a matrix of individual ultrasound transducer elements (10) with an area of 6x6 mm^2 or 7 x 7 mm^2 and that each ultrasound transducer element (10) is connected with a pulse generator (12) and a channel of an analog - digital unit and can be regulated and evaluated individually for the dynamic depth focusing and/or dynamic aperture adaptation.

2. Device in accordance with Claim 1, characterized in that the probes (PK1 PKn) are arranged in a water basin (96), which can be adjusted with the help of controlling elements (86, 88, 90) for the purpose of adjusting the waviness in relation to a lower side (78) of the material that is to be tested (70).

3. Device in accordance with Claim 1 or 2, characterized in that the water basin (96) with the help of a circulating sealing element such as lip seals with respect to the lower side (78) of the material that is to be tested (70).

4. Device in accordance with Claim 2 Oder 3, characterized in that the water basin (96) is fitted with sliding elements such as Gleitkufen in the direction of testing with respect to the underside (78) of the material that is to be tested (709, to prevent damages to the water basin due to very large unevennesses in the test specimen.

5. Device in accordance with at least one of the previous claims, characterized in that the probes (PK1 PKn) a cover a width in the range of 1000 mm < B < 5300 mm.

6. Device in accordance with at least one of the previous claims, characterized in that the probes (PK1 PKn) preferably have an active surface in the range of 30 mm x 150 mm.

7. Device in accordance with at least one of the previous claims, characterized in that the ultrasound transducer elements (10) are arranged with a distance in the range of 0.2 mm to 3 mm with respect to each other.

8. Device in accordance with at least one of the previous claims, characterized in that the probes (PK1 PKn) can be programmed to suit individual focal zones.

9. Device in accordance with at least one of the previous claims, characterized in that the probes (PK1 PKn) can be connected with the help of segment immersion technique to the material that is to be tested (78).

10. Device in accordance with Claim 1, characterized in that a complete wave front can be transmitted to at least one section of the sheet which is to be tested with the help of the large number of independent ultrasound elements,

- that a wave that is reflected by the structure of the sheet can be recorded with the help of the large number of mutually independent ultrasound elements ,
- that the transmitting and receiving unit has a digitalization unit for digitizing the signals that are received by the ultrasound elements in digitization steps,
- that the transmitting and receiving unit has a control unit for continuously changing the delay values and/or the number of ultrasound elements for every step of digitations (on the fly).

11. Device in accordance with Claim 1, characterized in that the delay values from a saved start delay (law of focuses for the surface position) to the end delay (law of focuses for the rear wall position) can be calculated with the help of a distance function 1/R. with R = Radius.

12. Device in accordance with Claim 10 or 11, characterized in that the delay values are saved in a reference table, in particular, in the case of complex coherence.

13. Device in accordance with at least one of the previous claims, characterized in that an aperture adaptation is possible through a linear change in the number of reception elements.

14. Device in accordance with at least one of the previous claims, characterized in that it is possible to trigger a starting of the change in the delay values and/or aperture adaption through the "time of flight" position of the surface interface echoes.

15. Device in accordance with at least one of the previous claims, characterized in that the reception unit has a summation unit for summing up the various focused transmitter shots to form a signal by using a digital TGC function.

16. Device in accordance with at least one of the previous claims, characterized in that delay values can be defined by functional dependencies such as a Bezier function, polynomial or other type of function, whereby the function uses the element indices as argument and outputs the delay values as the result, while parameters are set depending on the application.

17. Device in accordance with at least one of the previous claims, characterized in that delay values can be created through a linear combination of one or more instances of a method or through the linear combination of various instances of several of the said methods.

18. Device in accordance with at least one of the previous claims, characterized in that the recording elements have an electronic storage module (42, 46) for caching the data.

Application number / numéro de demande: EP2009056584

Figures: Fig. 2, 7

Pages:

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received with this application
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10ème étage)

Block diagram of 128 channel phase board

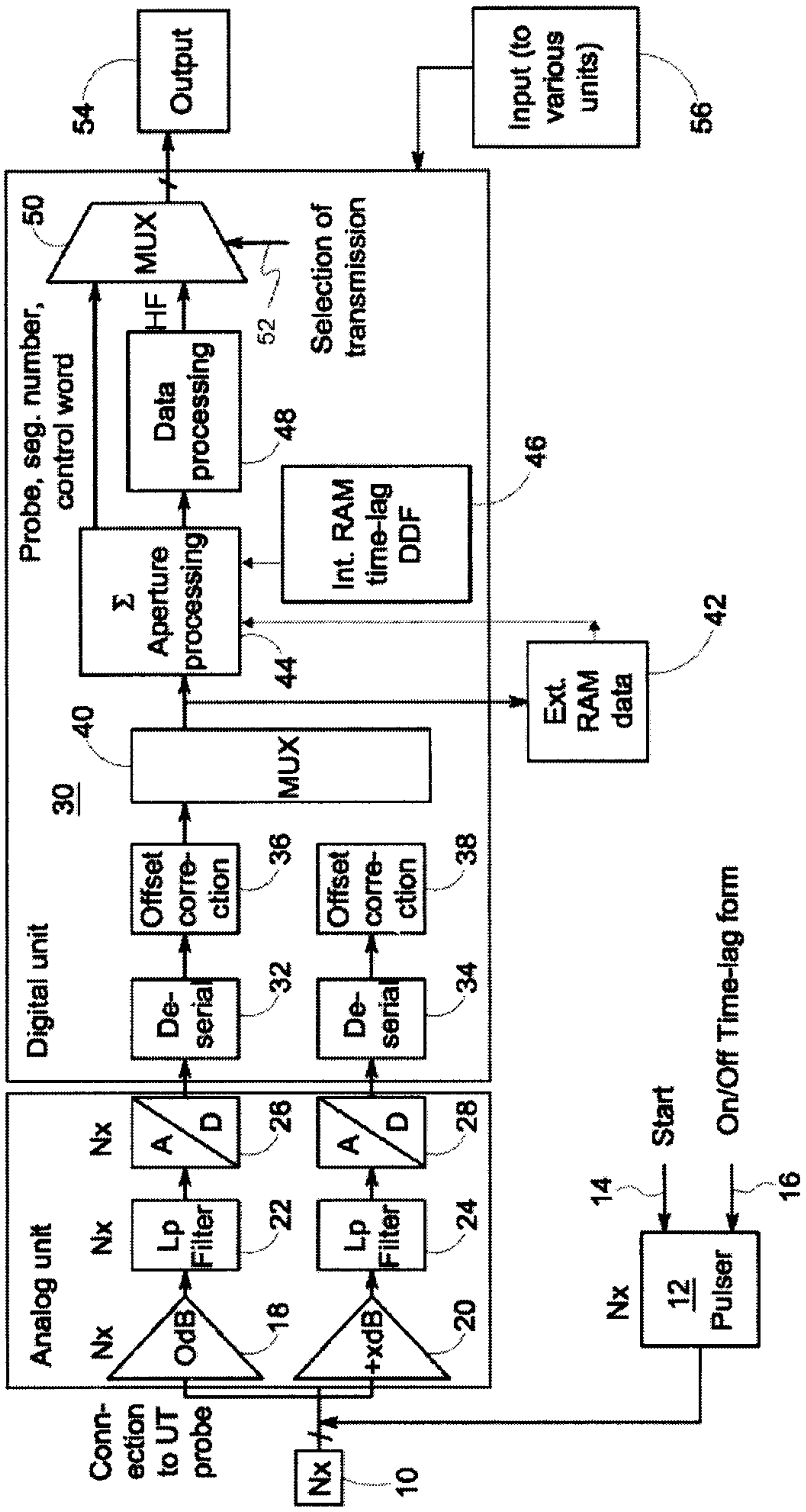


FIG. 1

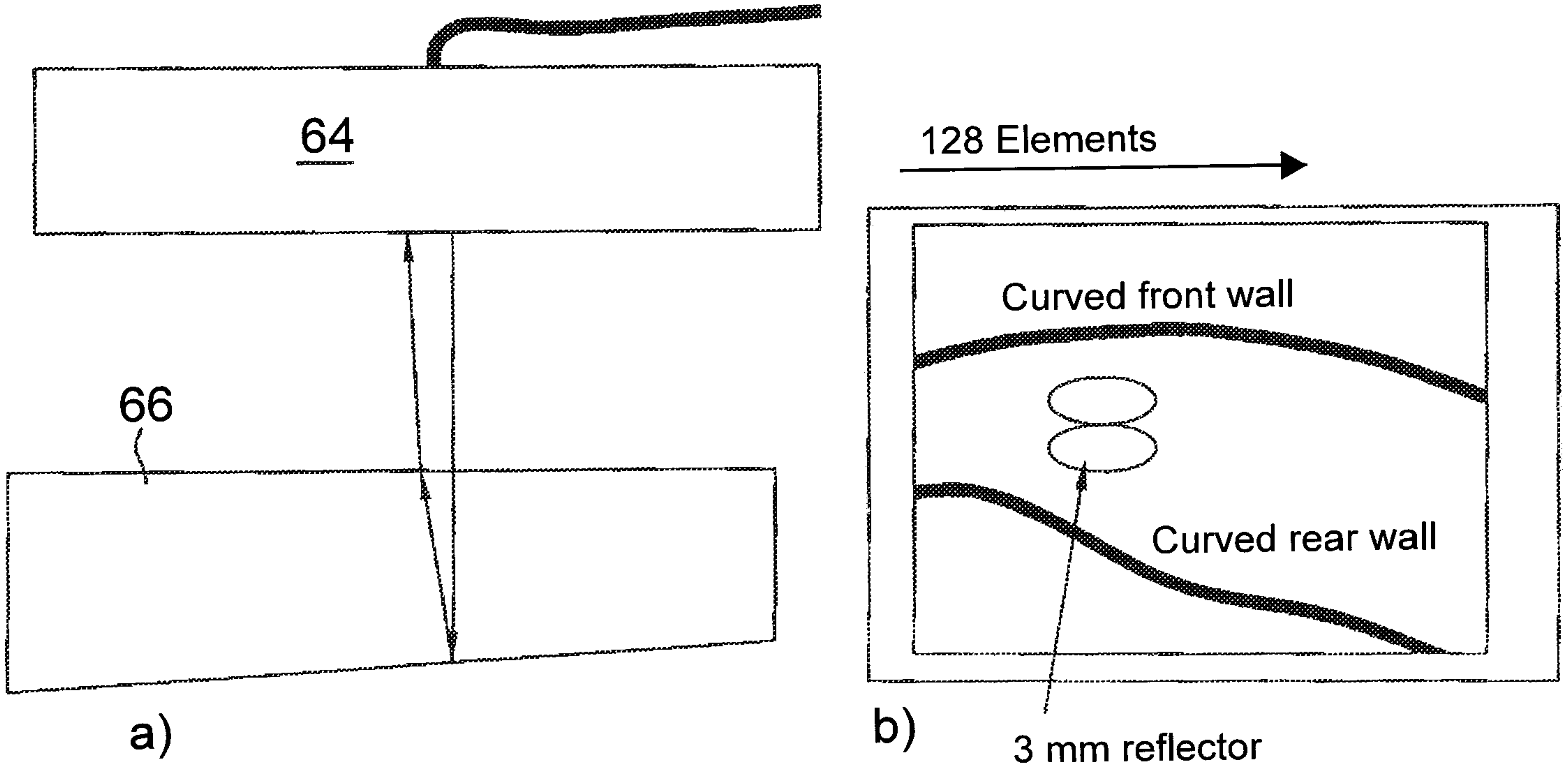
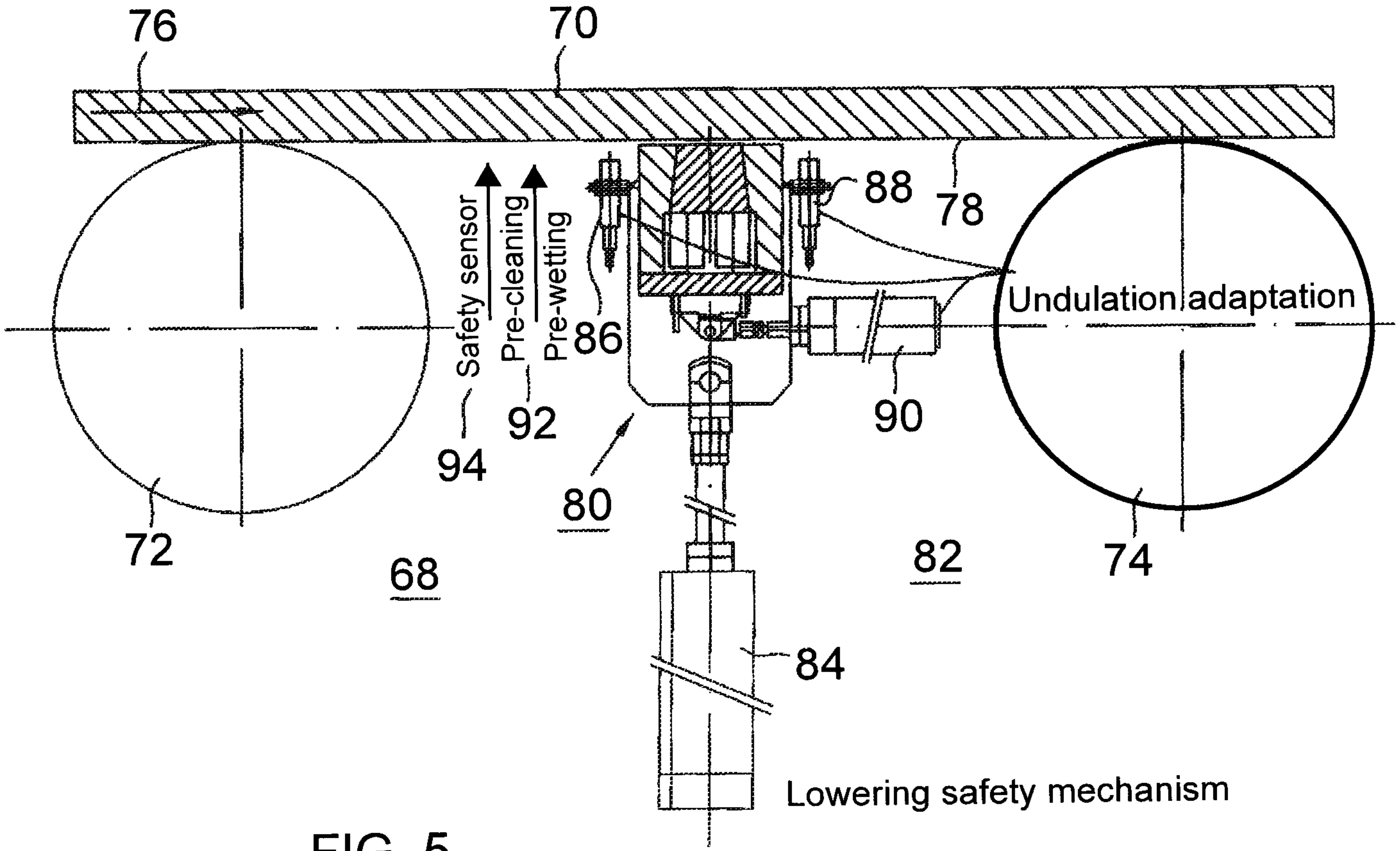

64
66
a)
128 Elements
Curved front wall
Curved rear wall
b)
3 mm reflector

FIG. 4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70
88
78
Safety sensor
Pre-cleaning
Pre-wetting
86
Undulation adaptation
94
92
90
80
72
74
68
82
84
Lowering safety mechanism

FIG. 5

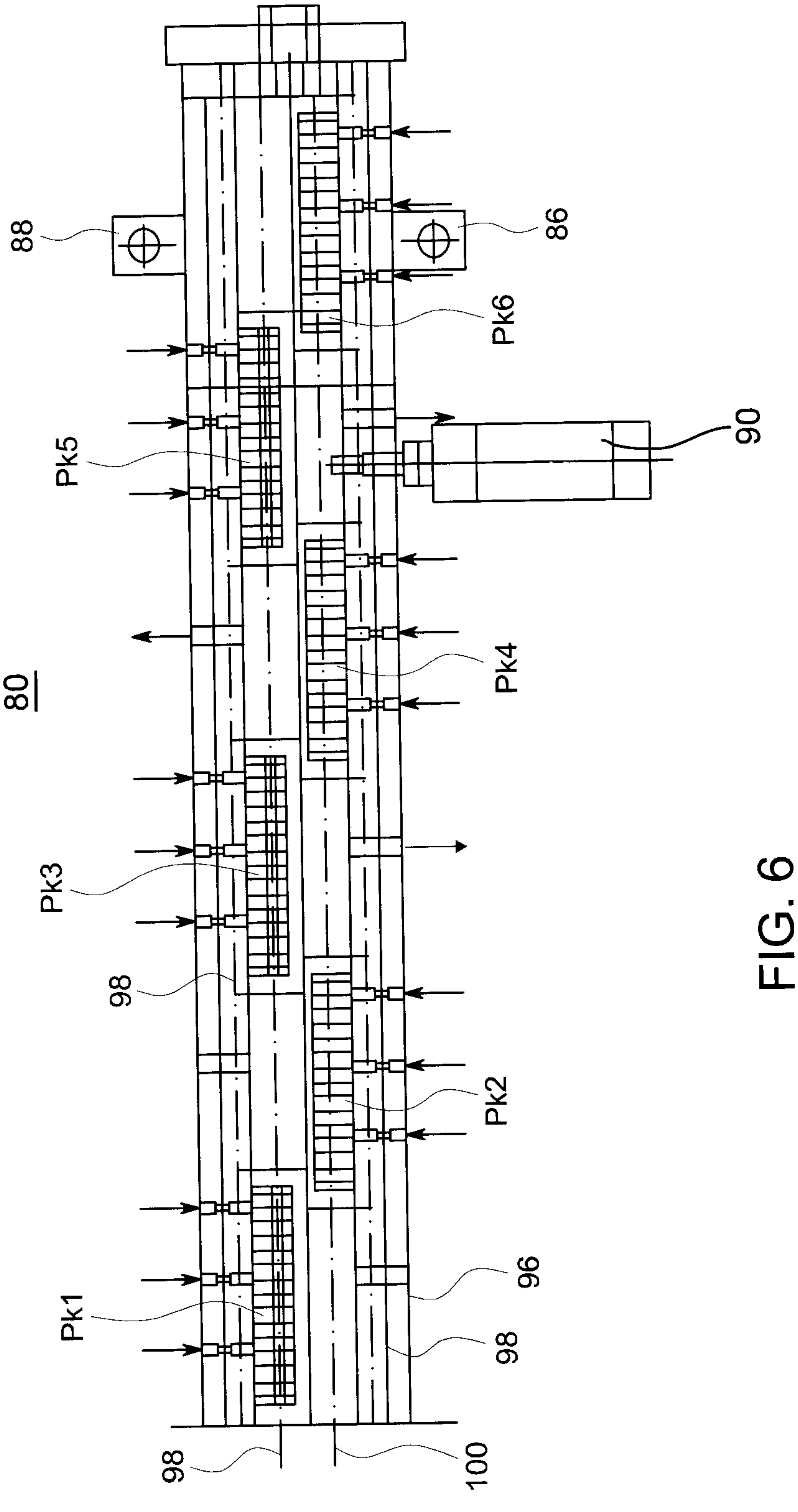

FIG. 6

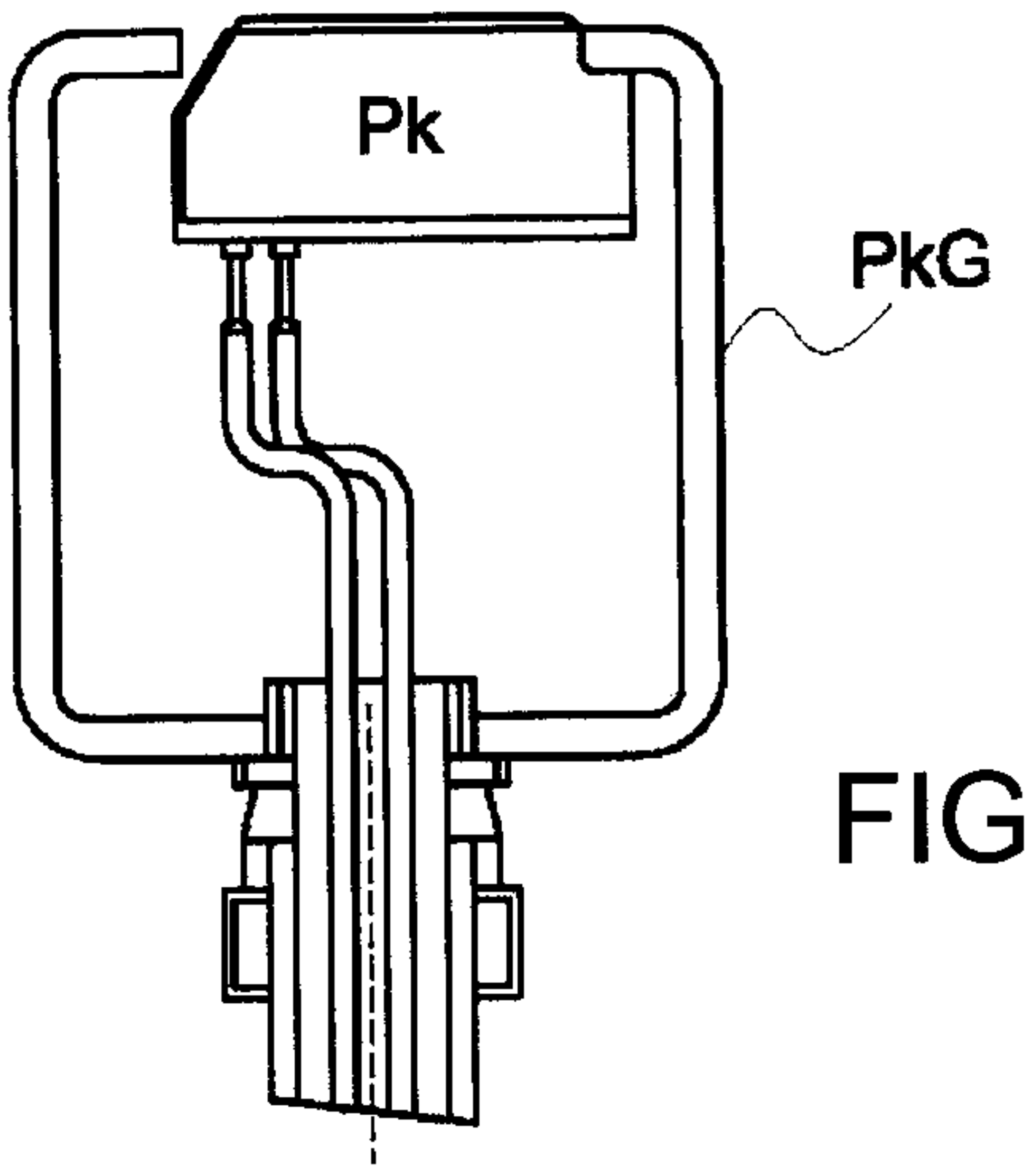

FIG. 9a

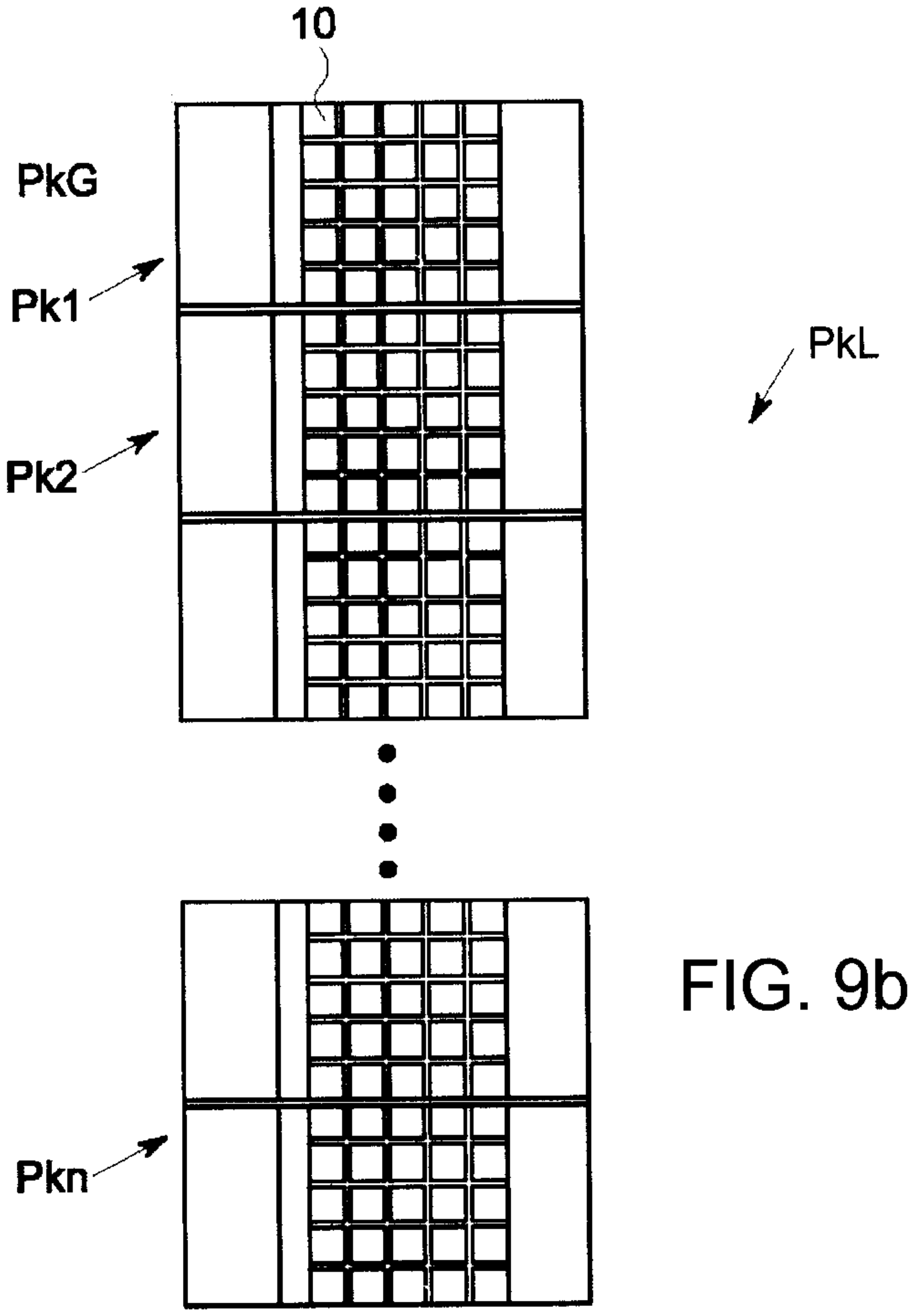

FIG. 9b

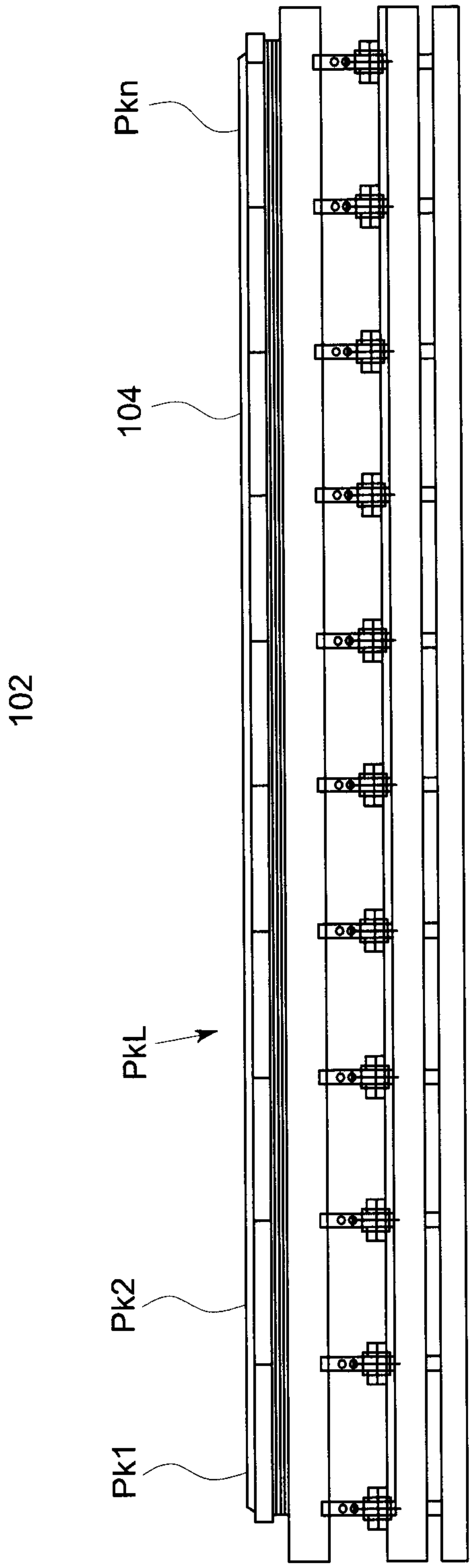

FIG. 10

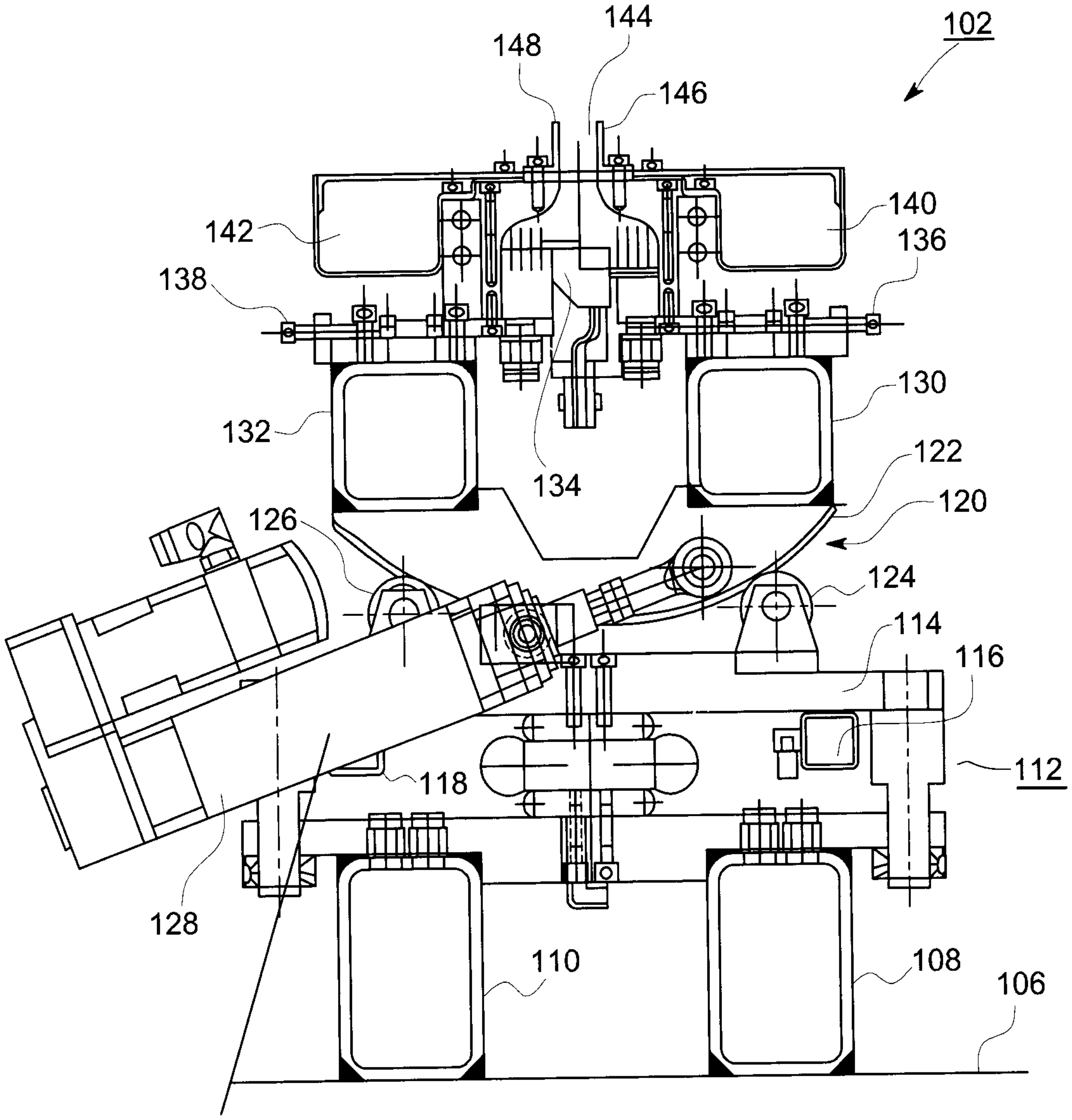
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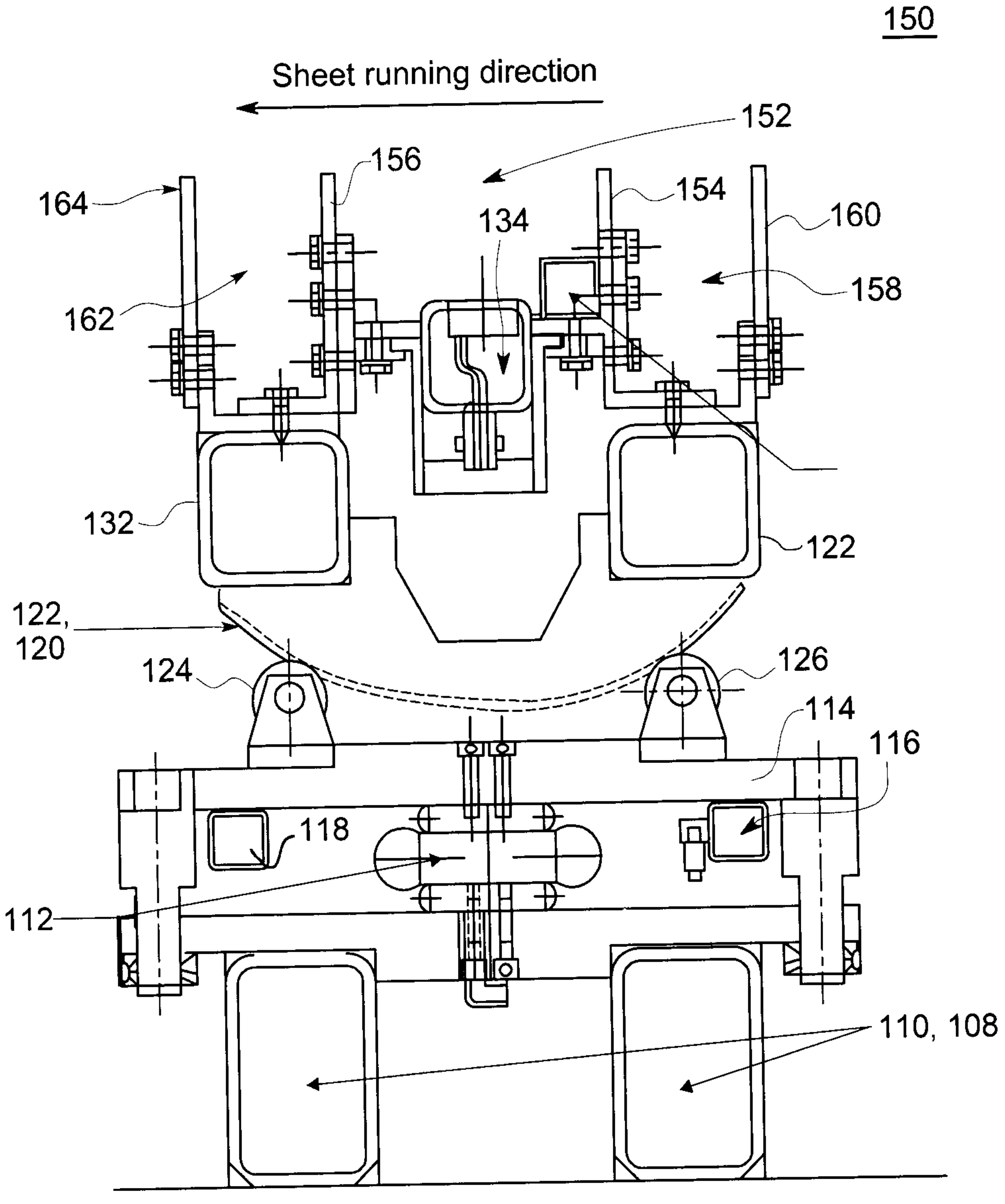
FIG. 11


150
Sheet running direction
152
156
154
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110, 108

FIG. 12

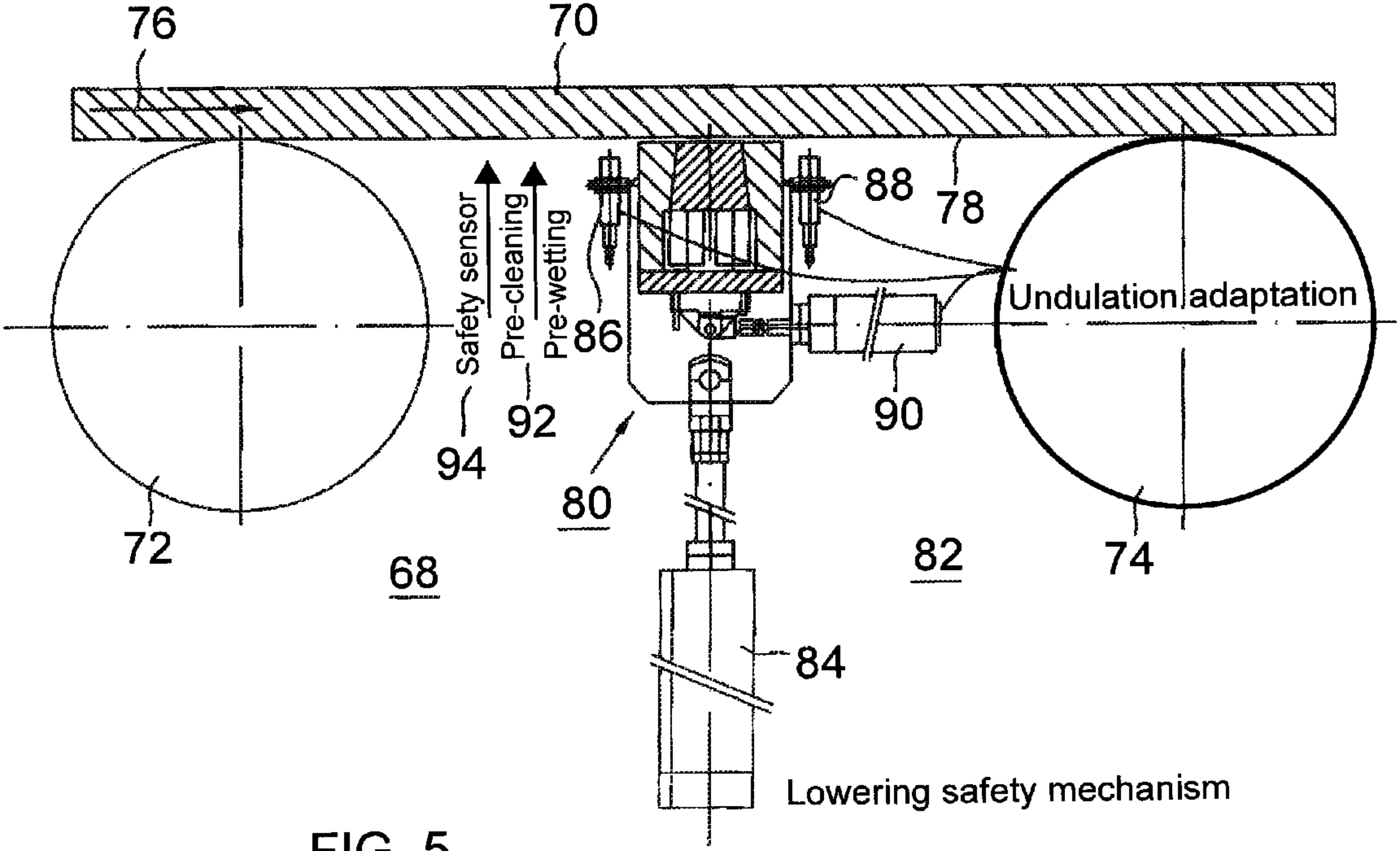

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FIG. 5