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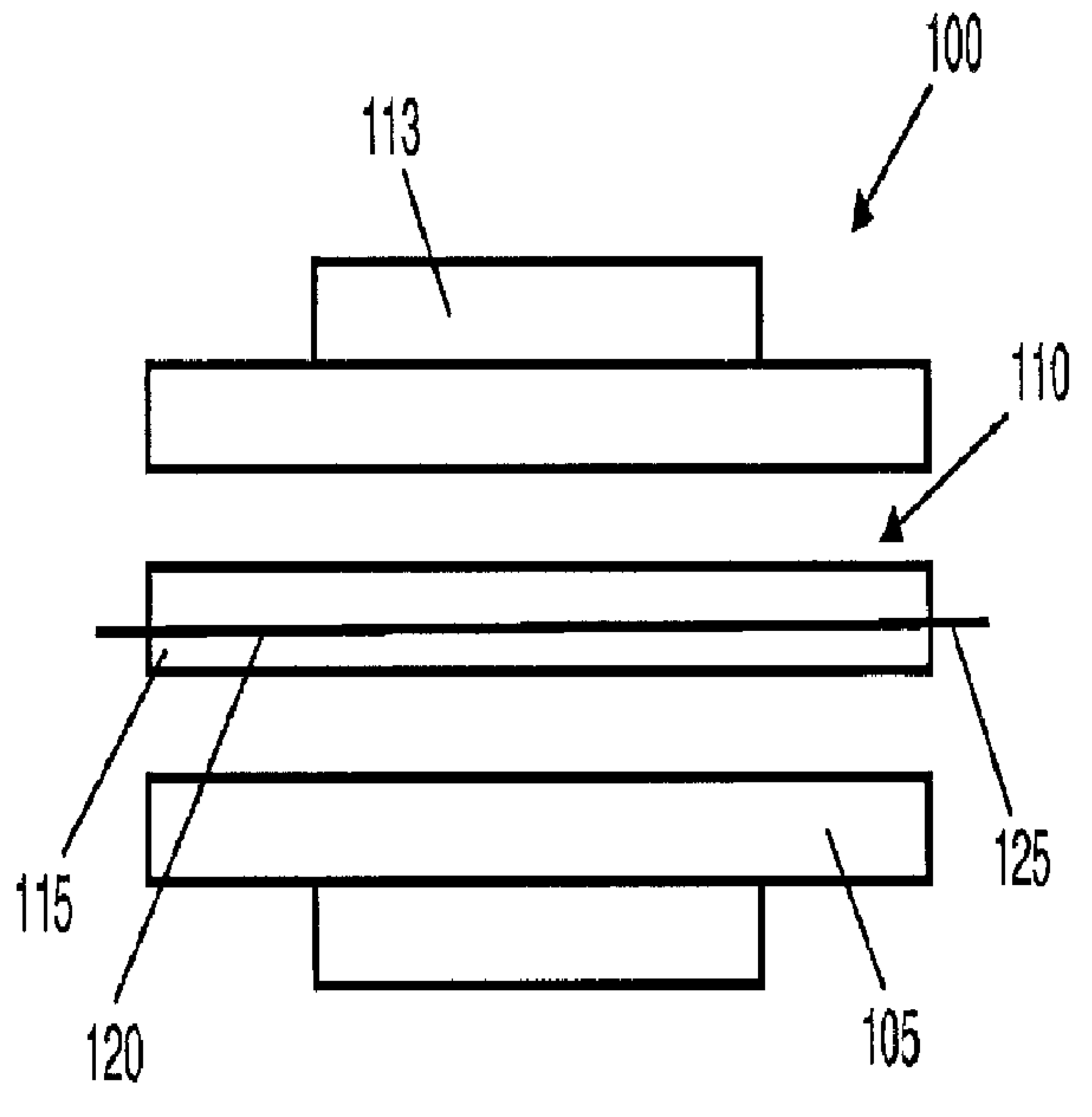

(57) Abrégé/Abstract:
A wired reamer for use on a downhole drillstring is disclosed. In some embodiments, the reamer includes a reamer body comprising a pathway therethrough and wiring located within the pathway for transmitting at least one of power or communications. In other embodiments, the reamer includes a reamer body comprising a pathway enclosed within the reamer body, wiring located within the pathway for transmitting at least one of power or communications, a sensor and a processor located within the reamer body. The sensor is connected with the wiring for transmitting data measured by the sensor through the wiring, and the processor is connected with the wiring for receiving the data from the sensor.

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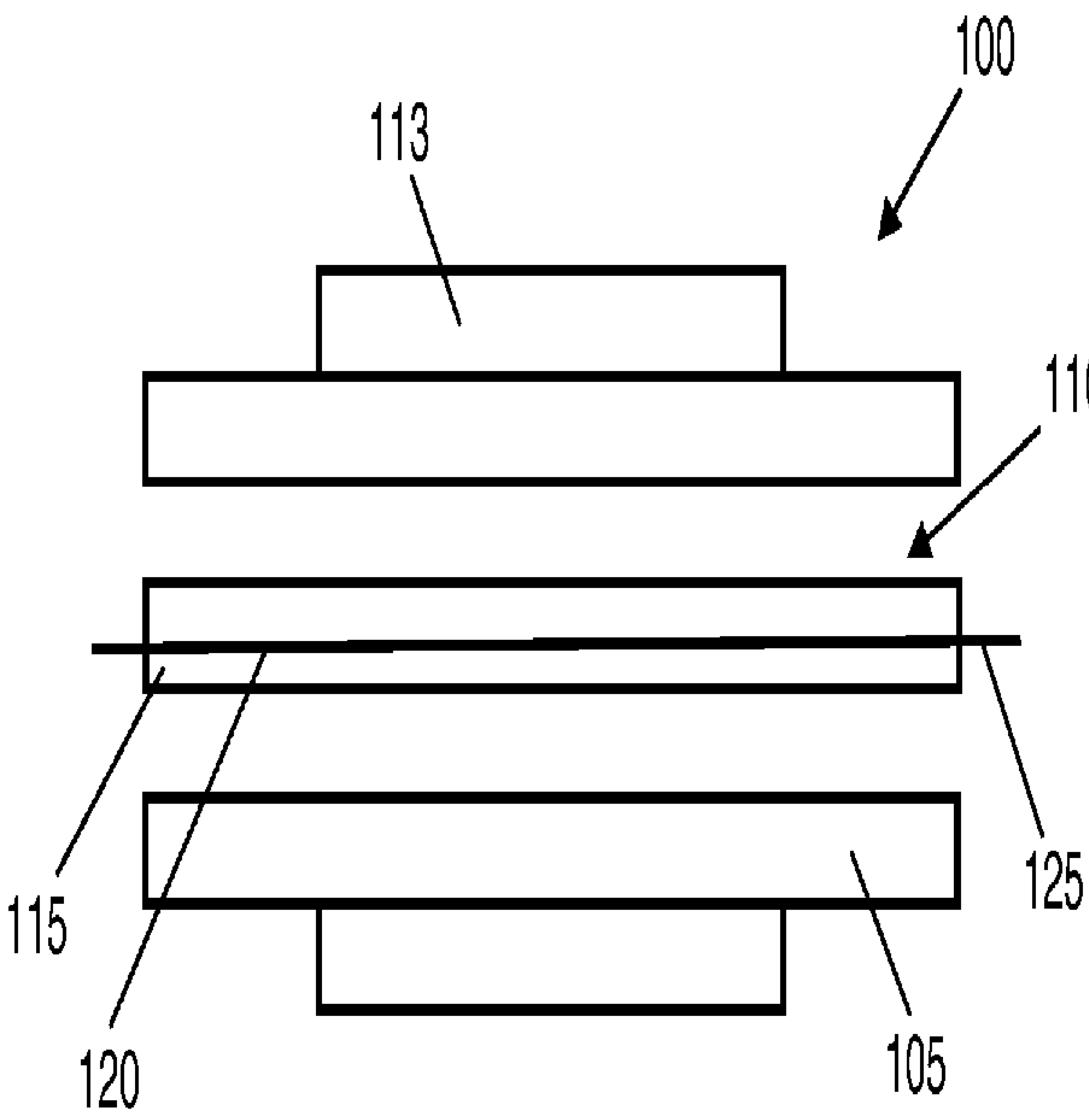

FIG. 1

(57) Abstract: A wired reamer for use on a downhole drillstring is disclosed. In some embodiments, the reamer includes a reamer body comprising a pathway therethrough and wiring located within the pathway for transmitting at least one of power or communications. In other embodiments, the reamer includes a reamer body comprising a pathway enclosed within the reamer body, wiring located within the pathway for transmitting at least one of power or communications, a sensor and a processor located within the reamer body. The sensor is connected with the wiring for transmitting data measured by the sensor through the wiring, and the processor is connected with the wiring for receiving the data from the sensor.

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A WIRED SMART REAMER

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

BACKGROUND

In the drilling of oil and gas wells, it is frequently necessary or desirable to "ream" a borehole that has been previously created by a drill bit or other cutting tool so as to ream out ledges, remove sloughed areas and key seats, straighten the borehole, stabilize the drill string, and enlarge the borehole. For those reasons, a reamer may be positioned behind a drill bit, or other cutting structure, on the drilling assembly so as to ream the hole after the bit has formed the borehole. It is sometimes preferred that such a reaming step be performed as the bit is being withdrawn from the borehole, that process being referred to as "backreaming." Also, it is sometimes necessary to run a reamer on a subsequent trip to straighten or clean up the borehole. In casing drilling applications, the reamer is needed to drill the primary hole before the casing string.

When drilling oil and gas wells using a rotary steerable tools, it is desirable to ream the borehole as close to the bit as possible so as to minimize the distance between the bit borehole and the reamer borehole. Because rotary steerable tools commonly need to communicate with the measurement-while-drilling (MWD) system, it is important for all tools located between the rotary steerable tool and the MWD telemetry system to allow the transmission of power and communications through the tool.

There are three main categories of reamers. Fixed blade reamers, including near bit reamers, have fixed blades that do not move or expand. A fixed blade reamer cuts a larger bore because it has a larger outer diameter than the pilot bit. The fixed blade reamer can be used to enlarge a borehole by a relatively small amount. Since the reamer blade is fixed, the borehole opening is at the surface or adjacent a larger hole section. A fixed blade reamer can be used to ream out ledges, straighten boreholes, remove key seats and remove sloughed areas. Roller reamers have roller cutters that are mounted to a main body and can be used to enlarge the bore, ream out ledges, straighten boreholes, remove key seats and sloughed areas, as well as stabilize a drilling string and reduce the overall torque of the drill string. Extendable blade or expandable reamers, including underreamers, have arms that may be extended on surface or downhole to a predetermined diameter to cut a larger bore. An extendable blade reamer can be used to enlarge the bore by a substantial amount, ream out ledges, straighten boreholes, and remove key seats and sloughed areas.

Conventional underreamers are typically used in conjunction with a pilot drill bit which is positioned below or downstream of the underreamer. A underreamer can be used to drill and expand the borehole below a cased section or, as in casing drilling applications, can be used to drill the well bore from the surface or below a larger cased section. In casing drilling applications, a drilling assembly including at least a bit and reamer are used to open the borehole below the casing string. The casing string is used as a replacement for the drill pipe, transferring fluid and torque down to the drilling assembly. After the borehole is completed, the underreamer arms are retracted and the drilling assembly is recovered to surface.

The underreamers usually have hinged arms with roller cones and PDC cutters attached thereto. The arms are actuated by mechanical or hydraulic forces acting on the arms, causing the arms to pivot at an end opposite the cutting end of the arms and thereby extend or retract. These arms can be forced out against the formation by a piston or driving arm. In conventional operations, the arms of the underreamer are retracted to allow the tool to pass through a smaller hole section or cased hole section. Once the tool has passed through the smaller hole or cased hole section, the underreamer arms are extended. The pilot bit drills the borehole, while at the same time, the underreamer enlarges the borehole formed by the bit. Typical examples of these types of underreamers are found in U.S. Patents 3,224,507, 3,425,500 and 4,055,226.

In casing drilling applications, the underreamer is opened on surface with a casing string connected behind the reamer. The casing string is used as a replacement for conventional drill pipe. The underreamer needs to be able to close back to a size that will allow the drilling assembly to be removed from the well bore. The drilling assembly may need to be removed if a portion of the assembly fails or if the well bore is completed.

Conventional reamers have several disadvantages. If a reamer's cutting structure experiences wear, the hole geometry may not be opened to the desired size. Also, the reamer's cutting structure may not be selected correctly to properly stabilize a drilling assembly. Moreover, a conventional underreamer may fail to deploy fully or retract fully. A conventional underreamer typically has rotary cutter pocket recesses formed in the body for storing the retracted arms and roller cone cutters when the tool is in a closed state. The pocket recesses tend to fill with debris from the drilling operation, which hinders collapsing of the arms. If the arms do not fully collapse, the drill string may easily hang up in the borehole when an attempt is made to remove the string from the borehole. In casing drilling applications, if the reamer arms do not collapse, the underreamer may hang up on the casing string.

The activation and deactivation method of the arms of an underreamers may also create drilling operational limitations. Some underreamers use a ball to assist with the activation and deactivation of the reamer arms. Although a ball drop can be used to lock the reamer arm position, the underreamer cannot be used below tools that have no throughbore to permit passage of the ball. In addition, there may be a limitation to the number of cycles that the reamer arms can be activated and deactivated. Moreover, some underreamers are designed to automatically expand when drilling fluid is pumped through the drill string. Underreamers that actuate in response to flow alone are very sensitive to the flow. Thus, these underreamers may open and close every time the pumps are turned on or off. The primary operational limitation may be the ability to maintain the full deployment of the reamer arms under the required flow rate needed for drilling. Many underreamers have limited or no indication provided at the surface that the underreamer is in the fully-expanded or collapsed position. Thus, in some applications, it may be desirable to control when the underreamer expands or collapses regardless of the flow, rather than rely on automatic expansion in response to the drilling fluid. It may also be desirable to vary the size of the hole being opened downhole depending on the well bore location.

Another method for enlarging a borehole below a previously cased borehole section includes using a winged reamer behind a conventional drill bit. In such an assembly, a conventional pilot drill bit is disposed at the lowermost end of the drilling assembly with a winged reamer disposed at some distance behind the drill bit. The winged reamer generally comprises a tubular body with one or more longitudinally extending "wings" or blades projecting radially outwardly from the tubular body. Once the winged reamer has passed through any cased portions of the wellbore, the pilot bit rotates about the centerline of the drilling axis to drill a lower borehole on center in the desired trajectory of the well path, while the eccentric winged reamer follows the pilot bit and engages the formation to enlarge the pilot borehole to the desired diameter.

Yet another method for enlarging a borehole below a previously cased borehole section includes using a bi-center bit, which is a one-piece drilling structure that provides a combination underreamer and pilot bit. The pilot bit is disposed on the lowermost end of the drilling assembly, and the eccentric underreamer bit is disposed slightly above the pilot bit. Once the bi-center bit has passed through any cased portions of the wellbore, the pilot bit rotates about the centerline of the drilling axis and drills a pilot borehole on center in the desired trajectory of the well path, while the eccentric underreamer bit follows the pilot bit and engages the formation to enlarge the pilot borehole to the desired diameter. The diameter of the pilot bit is made as large as possible for stability while still being capable of passing through the cased borehole. Examples of bi-center bits may be found in U.S. Patents 6,039,131 and 6,269,893.

As described above, winged reamers and bi-center bits include underreamer portions that are eccentric. A number of disadvantages are associated with this design. Due to directional tendency problems, the eccentric underreamer portions have difficulty reliably underreaming the borehole to the desired diameter. The bore geometry has a large amount of spiralization which increases the borehole torque and axial friction. With respect to a bi-center bit, the eccentric underreamer bit tends to cause the pilot bit to wobble and undesirably deviate off center, thereby pushing the pilot bit away from the preferred trajectory of drilling the well path. A similar problem is experienced with respect to winged reamers, which only underream the borehole to the desired diameter if the pilot bit remains centralized in the borehole during drilling.

In the oil and gas industry, it is desirable to detect and control the operational forces that act on a tool in order to determine whether a tool has sustained damaged, to limit the damage that the tool may experience, and/or to ensure that a particular operation is performed correctly. Sensors to detect vibration, axial forces, torsional forces, and bending forces, and to transmit that data real-time to the surface, can be used to identify when a drilling tool is experiencing forces that exceed its operational parameters. Drilling operations may then be modified to prevent or limit damage to the tool and/or to correct an ongoing operation.

To optimize the drilling operation and/or wellbore placement, it is desirable to be provided with information concerning the operational parameters of the drill string and the environmental conditions of the surrounding formation being drilled. For example, it is often necessary to frequently adjust the direction of the borehole while drilling, either to accommodate a planned change in direction, or to compensate for unintended and unwanted deflection of the borehole. In addition, it is desirable that the information concerning tool operation, the drilling environment, and formation type or characteristics be provided to the operator on a real time basis. The ability to obtain real time data measurements while drilling permits a relatively more economical and more efficient drilling operation. Therefore, it is important that any tool located between the MWD or LWD sensors and the MWD telemetry system allow the transmission of power and/or communications through the tool.

To obtain real time data while drilling, a collection of drilling tools and measurement devices commonly known as the bottom hole assembly (BHA) are positioned at the downhole end of the drill string. Typically, the BHA includes the drill bit, any directional or formation evaluation tools, deviated drilling mechanisms, mud motors, and weighted collars that are used in the drilling operation. A measurement while drilling (MWD) or logging while drilling (LWD) collar is often positioned just above the drill bit to take measurements relating to the borehole direction or formation properties of the borehole as it is being drilled. Measurements recorded from MWD and LWD systems may be transmitted to the surface in real-time using a variety of methods known to those skilled in the art. Once received, these measurements will enable those at the surface to make decisions concerning the drilling operation. Due to the limitations in transmitting information, it is common for the more detailed information or the tool reliability information to be stored for download when the tool is recovered on the surface.

Accordingly, various systems have been developed that permit downhole sensors to measure real time drilling parameters and to transmit the resulting information or data to the surface substantially instantaneously with the measurements. For example, mud pulse telemetry systems transmit signals from an associated downhole sensor to the surface through the drilling mud in the drill string. As another example, drill pipe with built-in telemetry, or hard wired pipe, transmits signals from the downhole sensor to the surface through wiring contained within the drill pipe wall. These telemetry systems and associated sensors may be located a significant distance from the drilling bit. The environmental information measured by the system may not necessarily correlate with the actual conditions surrounding the drill bit. Rather, the system is responding to conditions that are substantially spaced from the drilling bit. For instance, a conventional telemetry system may have a depth lag of up to or greater than 60 feet. As a result of this information delay, it is possible to drill out a hydrocarbon producing formation before detecting the exit, resulting in the need to drill several feet of borehole to get back into the pay zone. In response to this undesirable information delay or depth lag, various near bit sensor systems or packages have been developed which are designed to be placed adjacent or near the drilling bit. However, such near bit sensors continue to be located a spaced distance from the drill bit assembly that still introduces a lag in determining formation changes.

In order to use a near bit sensor system and permit real time monitoring and adjustment of drilling parameters, a system or method must be provided for transmitting the measured data or sensed information from the downhole sensor either directly to the surface or to a further telemetry system for subsequent transmission to the surface. Similarly, a system or method may need to be provided for transmitting the required electrical power to the downhole sensor system from the surface or some other power source. As a result, all of the tools in the directional BHA need the ability to transfer power and communications through their body, or the tools need to be located above the telemetry system. Conventional reamers available today do not have the ability to transmit power and communications through their body, and as a result, the placement of the underreamers has been a significant distance from the bit. In casing drilling applications, this means that the directional BHA below the casing string is very long and prone to operational issues, such as debris buildup and vibration.

Various systems have been developed for communicating or transmitting the information directly to the surface, for example, through an electrical line, wireline or cable to the surface. These hard-wire connectors provide a hard-wire connection from near the drilling bit to the surface; however, a wireline or cable must be installed in or otherwise attached or connected to the drill string. This wireline or cable is subject to wear and tear during use and thus may be prone to damage or even destruction during normal drilling operations. The drilling assembly may not be particularly suited to accommodate such wirelines, with the result that the wireline sensors may not be able to be located in close proximity to the drilling bit. Wirelines and wireline connectors by their very nature create blockages in the drillpipe, thus precluding some types of reamer activation mechanisms.

Systems have also been developed for the transmission of acoustic or seismic signals or waves through the drill string or surrounding formation. The acoustic or seismic signals are generated by a downhole acoustic or seismic generator. However, a relatively large amount of power is typically required downhole in order to generate a sufficient signal such that it is detectable at the surface. A relatively large power source must be provided downhole or repeaters used at intervals along the string to boost the signal as it propagates along the drill string.

Further, systems have been developed which require the transmission of electromagnetic signals through the surrounding formation. Electromagnetic transmission of the sensed information often involves the use of a toroid positioned adjacent the drilling bit for generation of an electromagnetic wave through the formation. As with acoustic and seismic signal transmission, the transmission of electromagnetic signals through the formation typically requires a relatively large amount of power, particularly where the electromagnetic signal must be detectable at the surface. Further, attenuation of the electromagnetic signals as they are propagated through the formation is increased with an increase in the distance over which the signals must be transmitted.

Hardwired drillpipe has also been developed which allows significant amounts of data to be transferred from downhole to the surface. These systems require that the hardwire be run the length of the drillstring and communicate with the drilling BHA. Communications across connections can be problematic, and given the large number of connections in a typical drill string, these systems can be prone to reliability and maintenance issues.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed description of the preferred embodiments of the invention, reference will now be made to the accompanying drawings in which:

FIG. 1 is a representative schematic of a wired reamer with power and/or communications wiring through the reamer flowbore in accordance with the present invention;

FIG. 2 shows the wired reamer of FIG. 1 with the power and/or communications wiring through the reamer body;

FIG. 3 is a representative schematic of a wired, adjustable blade reamer with power and/or communications wiring through the reamer flowbore in accordance with the present invention;

FIG. 4 shows the wired reamer of FIG. 3 with the power and/or communications wiring through the reamer body;

FIG. 5 shows the wired reamer of FIG. 1 with the power and/or communications wiring to the reamer flowbore;

FIG. 6 shows the wired reamer of FIG. 2 with the power and/or communications wiring to the reamer body;

FIG. 7 shows the wired reamer of FIG. 1 with the power and/or communications wiring contained within the reamer flowbore;

FIG. 8 shows the wired reamer of FIG. 2 with the power and/or communications wiring contained within the reamer body;

FIG. 9 shows the wired reamer of FIG. 1 with sensors;

FIG. 10 shows the wired reamer of FIG. 2 with sensors;

FIG. 11 shows the wired reamer of FIG. 3 with sensors;

FIG. 12 shows the wired reamer of FIG. 4 with sensors;

FIG. 13 shows the wired reamer of FIG. 1 with wireless sensors;

FIG. 14 shows the wired reamer of FIG. 2 with wireless sensors;

FIG. 15 shows the wired reamer with sensors of FIG. 9 with access to a processor;

FIG. 16 shows the wired reamer with sensors of FIG. 5 with sensors and access to a processor;

FIG. 17 shows the wired reamer of FIG. 7 with sensors and a processor;

FIG. 18 shows the wired reamer of FIG. 1 with controllers and actuators;

FIG. 19 shows the wired reamer of FIG. 2 with controller and actuators;

FIG. 20 shows the smart reamer of FIG. 15 with controllers and actuators;

FIG. 21 shows the smart reamer of FIG. 16 with controller and actuators;

FIG. 22 shows the smart reamer of FIG. 20 with controllers and actuators; and

FIG. 23 shows the smart reamer of FIG. 21 with controller and actuators.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following discussion is directed to various embodiments of the invention. Although one or more of these embodiments may be preferred, the embodiments disclosed should not be interpreted, or otherwise used, as limiting the scope of the disclosure, including the claims. In addition, one skilled in the art will understand that the following description has broad application, and the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to intimate that the scope of the disclosure, including the claims, is limited to that embodiment.

Certain terms are used throughout the following description and claims to refer to particular features or components. As one skilled in the art will appreciate, different persons may refer to the same feature or component by different names. This document does not intend to distinguish between components or features that differ in name but not function. The drawing FIGS. are not necessarily to scale. Certain features and components herein may be shown exaggerated in scale or in somewhat schematic form and some details of conventional elements may not be shown in interest of clarity and conciseness.

In the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to... ." Also, the term "couple" or "couples" is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection, or through an indirect connection via other devices and connections.

A wired reamer permits power and/or communications through the reamer to other downhole tools, to equipment on the surface, or to the reamer itself. The ability to pass power and/or communications through the reamer overcomes some limitations regarding where the reamer may be placed in a drilling BHA. Furthermore, positioning sensors on the reamer permits the collection of data relating to the tool operation, borehole geometry, drilling environment, and evaluation of the surrounding formations being drilled. The data may be transmitted to the surface or other telemetry tool using the through-tool communications and used to optimize the drilling operation, or stored inside the tool for later download. Moreover, data measured by the sensors may be transmitted to a processor located at the surface, on another downhole tool, or on the reamer itself. In such configurations, the reamer is "smart", meaning the reamer communicates with a processor for deciphering data collected by the sensors.

Furthermore, locating controllers and actuators on the reamer permits control of the reamer during drilling operations through direct command or feedback from algorithms developed as a function of the data measured by the sensors. Direct commands or feedback may be transmitted using the through-tool communications to the controllers, directing the controllers to actuate the actuators, as needed to optimize the drilling operation. For example, controllers on the reamer may extend or retract the reamer arms, or otherwise reconfigure the reamer to limit forces experienced by the reamer.

Monitoring the performance of the reamer may help to determine when the reamer experiences a physical failure, such as excessive cutting structure wear, failed roller bearings, broken reamer arms, or when the reamer arms are not fully extended or retracted. Monitoring of the performance of the drilling parameters may help to determine whether the weight on the reamer arms is too high or too low, the vibration of the reamer is in an unacceptable range, or the torque through the reamer arms is in an unacceptable range.

The wired reamer may be located between a measurement while drilling (MWD) telemetry system and an instrumented bit, rotary steerable, or logging while drilling (LWD) sensor. In rotary steerable drilling bottom hole assemblies (BHAs), a wired reamer may allow the reamer to be located closer to the bit, reducing the rat hole created. In casing drilling applications, a wired reamer may allow a shorter stick out of the straight or directional BHA.

In some embodiments of a wired reamer, power and/or communications are provided through the bore of the reamer or the body of the reamer to the tools located downhole of the reamer or to the reamer itself. The communication path may be through the reamer bore or embedded in the reamer body. Also, the short hop power and/or communication path may be a conductive wire, conductive rod, fiber optic line, sonic or acoustic path, vibration path, electromagnetic (EM) signal, or wireless transmission. In the case of a conductive wire or rod, the conductor may be insulated from the reamer housing.

FIG. 1 is a schematic of a representative embodiment of a wired reamer that permits power and/or communications through the reamer. Wired reamer 100 comprises a body 105 with a flowbore 110 therethrough and a cutting structure 113 along the outer surface of the body 105. A feedthrough assembly 115 extends through the flowbore 110. The feedthrough assembly 115 further comprises a protected pathway 120 surrounding at least a portion of the power and/or communications wiring 125. The wiring 125 permits power and/or communications to and/or from other tools positioned uphole or downhole of the reamer 100.

In this representative embodiment, the pathway 120 for the power and/or communications wiring 125 extends through the flowbore 110 of the wired reamer 100. In other embodiments, the pathway 120 for the wiring 125 may extend through the reamer body 105, rather than the flowbore 110. FIG. 2 shows the wired reamer 100, depicted in FIG. 1, with the pathway 120 for the power and/or communications wiring 125 extending through the body 105 of the reamer 100. Because the pathway 120 is located within the body 105, there is no need for a feedthrough assembly to house and protect the wiring 125, as depicted in FIG. 1.

Moreover, the representative embodiment depicted in FIG. 1 is a fixed blade reamer. In other embodiments, the reamer 100 may be another type of reamer, including an adjustable blade reamer. FIG. 3 is a schematic of a representative embodiment of a wired, adjustable blade reamer. Thus, the reamer 100 further comprises arms 130 that may retract and extend. As shown, the arms 130 open from the right, which corresponds to the downhole end of the reamer 100. Alternatively, the arms 130 may open from the left, or the uphole end of the reamer 100, or bow out from the center of the reamer 100. The arms 130 further comprise cutting structures 113. Although depicted in FIG. 3 as positioned on the arms 130, the cutting structures 113 may alternatively, or additionally, be positioned on the reamer body 105 uphole or downhole of the arms 130.

As described above, the pathway 120 for the wiring 125 may extend through the reamer body 105, rather than through the flowbore 110. FIG. 4 shows the reamer 100, depicted in FIG. 3, with the pathway 120 for power and/or communications wiring 125 extending through the body 105 of the reamer 100. Because the pathway 120 is located within the body 105, there is no need for a feedthrough assembly to house and protect the wiring 125, as depicted in FIG. 3.

Power and/or communications need not be contiguous through a reamer, as they are depicted in FIGS. 1 through 4. Instead, power or communications may be provided through the reamer. Also, power and/or communications need not pass through the reamer, but instead may only be provided to the reamer. FIG. 5 shows the wired reamer 100, depicted in FIG. 1, with the pathway 120 for the power and/or communications wiring 125 extending to, but not through, the flowbore 110 of the reamer 100. Similarly, FIG. 6 shows the wired reamer 100, depicted in FIG. 2, with the pathway 120 for the power and/or communications wiring 125 extending to, but not through, the body 105 of the reamer 100. Moreover, power and/or communications need not pass through or to the reamer, but instead may be contained entirely within the reamer. FIG. 7 shows the wired reamer 100, depicted in FIG. 1, with the pathway 120 for the power and/or communications wiring 125 contained within the flowbore 110 of the reamer 100. Similarly, FIG. 8 shows the wired reamer 100, depicted in FIG. 2, with the pathway 120 for the power and/or communications wiring 125 contained within the body 105 of the reamer 100.

To optimize a drilling operation and/or formation evaluation, it is desirable to be provided with information relating to the operational parameters of the reamer as well as formation data from the surrounding formation being drilled. Therefore, in some embodiments, the instrumented, wired reamer is fitted with sensors to collect such information. These embodiments may be applicable to all three types of reamers, fixed blade, adjustable, and expandable. Power for operation of the sensors may be provided by a power source connected to the reamer, such as a downhole power generator or battery pack, or from the surface via wireline or hard wired tubulars. Alternatively, the power source may be located on the wired reamer itself.

Sensors may be positioned within the reamer as well as on its outer surface, including the arms. For instance, some sensors measuring formation data, are optimized by contact of the wellbore wall, where as other sensors work best centralized in the borehole. Sensors may be positioned on the reamer outer surface below or above the reamer arms and/or on the reamer arms. Other sensors can be used to monitor drilling or environmental data. For instance, to monitor the gauge and the potential smoothness of the borehole, sensors, specifically hole calipers, can be positioned above the arms, in the arms, or below the arms. The hole caliper sensors may be simple mechanical sensors such as a spring sensor, or more complex acoustic calipers which depend on pulse-echo, pitch/catch, or other data acquisition techniques. In measuring the caliper, mechanical sensors are best situated in the arms while acoustic sensors are best positioned in the body of the reamer. Sensors may be positioned on the reamer to monitor and report other information, such as the positioning, e.g. open, closed, and partially open, of the reamer arms and forces that act on the tool, such as vibration, weight on the reamer arms, torque on the reamer arms, rpm of the tool, temperature, pressure and/or stress/strain across the tool.

Certain types of formation evaluation sensors may be better suited to placement on the body of the reamer versus the reamer arms. For instance, certain resistivity sensors are better suited being placed on the arms of the reamer versus the body of the reamer ,whereas other types of resistivity devices work best centered in the borehole and thus on the reamer body. This is not to say, however, that these sensors will only work in these locations. Other formation evaluation sensors that may be positioned in the reamer include nuclear porosity, sonic, magnetic imaging and formation testing type sensors.

Information collected from the sensors may be stored in a memory chip located in the reamer. The information may be retrieved using an external port or wireless communication at the surface when the reamer is removed from downhole to the surface. Additionally or alternatively, the information collected may be transmitted using the through-tool communications to another storage device, whether located on another downhole tool or at the surface. Intertool communications are done either electrically through a hardwire connection or via other communications techniques such as short hop EM or acoustic transmission. Transmitting the information to the surface may be done real time using various communications techniques such as a mud pulse telemetry, acoustic telemetry, electro-magnetic induction, wireline, fiber optics, or hard wired tubulars.

FIG. 9 shows the wired reamer 100 of FIG. 1 with sensors for data collection. Wired reamer 100 further comprises sensors 140 located along the reamer 100. As shown, the sensors 140 are positioned on the outer surface of reamer 100, uphole of the cutting structure 113, downhole of the cutting structure 113, and on the cutting structure 113. The wired reamer 100 further comprises a cross-over 145, which permits data collected by sensors 140 to be communicated to the power and/or communications wiring 125, which, in this embodiment, extends through the feedthrough assembly 115 inserted through in the reamer flowbore 110.

Similarly, FIG. 10 shows the wired reamer 100 of FIG. 2 with sensors for data collection. In this embodiment, the pathway 120 for the power and/or communications wiring 125 passes through the reamer body 105. Because the wiring 125 passes through the reamer body 105, rather than the reamer flowbore 110, a cross-over between the sensors 140 and the wiring 125 is not necessary.

FIG. 9 and FIG. 10 depict fixed blade reamers. As discussed above, the reamer may be another type of reamer, including an adjustable blade reamer. Moreover, a wired, adjustable blade reamer, such as those depicted in FIG. 3 and FIG. 4, may be configured with sensors for data collection. FIG. 11 and FIG. 12 depict the wired, adjustable blade reamer 100 of FIG. 3

and FIG. 4, respectively, with sensors 140 positioned on the reamer 100 and, in the case of FIG. 11, the cross-over 145 coupled to the sensors 140 and the wiring 125.

The embodiments exemplified by FIG. 9 and FIG. 11 comprise a hard-wired connection, namely the cross-over 145, between the sensors 140 and the power and/or communications wiring 125. In other embodiments, this connection may be wireless, instead of hard-wired. For example, FIG. 13 shows the wired reamer 100 with sensors 140, depicted in FIG. 9, with a wireless connection 150, in place of the cross-over 145, between the sensors 140 and the wiring 125. The wireless connection 150 further comprises a source 155 and a receiver 160 for transmitting and receiving, respectively, data collected by the sensors 140 from the sensors 140 to the wiring 125.

Similarly, the hard-wired connection between the sensor(s) 140 located on the cutting structure 113 and the power and/or communications wiring 125 extending through the reamer body 105 of the embodiments exemplified by FIG. 10 and FIG. 12 may be replaced by a wireless connection. For example, FIG. 14 shows the wired reamer 100 with sensors 140, depicted in FIG. 10, with a wireless connection 150, in place of a hard-wired connection, between the sensor(s) 140 located on the cutting structure 113 and the wiring 125. As previously described, the wireless connection 150 further comprises the source 155 and the receiver 160 for transmitting and receiving, respectively, data collected by the sensors 140 from the sensors 140 to the wiring 125.

Power and/or communications need not be contiguous through a reamer, as they are depicted in FIGS. 9 through 14. Instead, power or communications may be provided through the reamer. Also, power and/or communications need not pass through the reamer, but instead may only be provided to the reamer, as depicted in FIG. 5 and FIG. 6. Moreover, power and/or communications need not pass through or to the reamer, but instead may be contained entirely within the reamer, as shown in FIG. 7 and FIG. 8.

A processor may be used to collect, process, analyze and store information measured by downhole sensors. Therefore, in some embodiments, the wired reamer with sensors is provided with access to a processor via its through-tool communications. In such embodiments, the reamer is referred to as "smart". The processor may be positioned on the surface, located on another downhole tool, or in the smart reamer itself.

Data collected by the sensors located on the smart reamer is transmitted to the processor via the through-tool communications. Data collected by sensors located on other downhole tools may also be transmitted to the processor via the through-tool communications of the reamer. Alternatively, information collected from the sensors, including those located on the reamer and other downhole tools, may be stored in a memory chip located in the reamer. The information may be retrieved from this memory chip using an external port or wireless communication at the surface or when the reamer is removed from downhole to the surface. Additionally or alternatively, the information collected may be transmitted using the thru-tool communications to another storage device, whether located on the surface or on another downhole tool. Inter-tool communications may be accomplished either electrically through a hardwire connection or via other communications techniques, such as short hop EM or acoustic transmission. Transmitting the information to the surface may be done real-time using various communications techniques, such as mud pulse telemetry, acoustic telemetry, electro-magnetic induction, wireline, fiber optics, or hard-wired tubulars. However the data may be retrieved from the sensors, the data is ultimately transferred to the processor for processing and analysis.

FIG. 15 shows the wired reamer with sensors of FIG. 9 with access to a processor via the through-tool communications of the reamer. As previously described, wired reamer 100 comprises the flowbore 110 therethrough, the cutting structure 113 along the outer surface of the body 105, and the sensors 140 also positioned along the reamer 100. The feedthrough assembly 115 extends through the flowbore 110. The feedthrough assembly 115 further comprises the pathway 120 surrounding at least a portion of the power and/or communications wiring 125. The wiring 125 permits power and/or communications to and/or from other tools positioned uphole or downhole of the reamer 100, including a processor 165. The processor 165 may be located at the surface or on another downhole tool. Data collected by sensors 140 on the reamer 100 and sensors located on other downhole tools with connectivity to the power and/or communications wiring 125 of the reamer 100 is transmitted to the processor 165 via the power and/or communications wiring 125.

FIG. 16 shows the wired reamer of FIG. 7 with sensors and access to a processor via the through-tool communications of the reamer. The sole distinction between FIG. 15 and FIG. 16 relates to the power and/or communications wiring 125 of the reamer 100. In FIG. 15, the wiring 125 extends through the reamer 100, whereas in FIG. 16, the wiring 125 extends to, but not through, the reamer 100. In contrast to both FIG. 15 and FIG. 16, FIG. 17 shows the wired reamer of FIG. 5 with sensors and a processor. The embodiments exemplified by FIG. 17 comprise the power and/or communications wiring 125 contained within the reamer 100, rather than extending through or to the reamer 100. Thus, in the embodiments exemplified by FIG. 17, the processor 165 is necessarily located within the reamer 100.

As with previously described embodiments, power and/or communications need not be contiguous through the smart reamer, as they are depicted in FIG. 15. Instead, power or communications may be provided through the smart reamer. Also, power and/or communications need not pass through the smart reamer, but instead may only be provided to the reamer, as depicted in FIG. 16. Moreover, power and/or communications need not pass through or to the smart reamer, but instead may be contained entirely within the reamer, as depicted in FIG. 17. Also, as with previously described embodiments, the smart reamer may be a fixed blade reamer, as illustrated in FIGS. 15 through 17, an adjustable blade reamer, or another type of reamer. In embodiments of the smart reamer having communications through or to the reamer, the processor may be located at the surface, on another downhole tool, or on the reamer itself. In embodiments of the smart reamer having communications contained within the reamer, the processor is necessarily located on the reamer itself.

To optimize a drilling operation and/or wellbore placement, it is desirable to control the operation of the reamer. Therefore, in some embodiments of the wired reamer, controllers and actuators are positioned in the reamer. The controllers and actuators may be electrical, hydraulic, mechanical, or other suitable type known in the industry. A signal may be sent to a controller, causing the controller to actuate an actuator, thereby controlling the operation of the reamer. For example, a signal may be sent to a controller, causing the controller to actuate an actuator to extend, retract, and/or lock the reamer arms.

In some embodiments, the signal may be a direct command originating from an operator at the surface. The direct command may be sent to a controller located on the reamer through any number of communication techniques, such as mud pulse, EM, acoustic, or hard-wired tubulars. Upon receipt of the direct command, the controller may actuate an actuator, also located on the reamer, causing the actuator to react in a desired manner, e.g. to retract the reamer arms.

The various means for actuating the actuators include, but are not limited to, electric motors, internally isolated hydraulic actuators, borehole fluid driven actuators, pressure actuated devices, or drill string driven actuator devices. For example, the reamer arms may be activated using hydraulic flow or pressure against an internal piston, which in turn drives the reamer arms out. Moreover, a ball drop device may be used to assist with opening, closing or locking the position of the reamer arms. As another example, an electric actuator may be used to limit the movement of the reamer arms and to lock the reamer in an open, closed or partially open position. The electrical actuator may be a solenoid, switch, or circuit. As still another example, the reamer arms may be actuated using an electric motor. A sensor may be used to determine the position of the reamer arms to confirm proper operation of the tool. As another alternative, electrical valves may be used to change the piston area of the reamer, thus changing the activation flow or pressure needed to engage the reamer arms. As still another alternative, a swash plate pump may be used to activate the reamer arms. Electrical valves may control the activation of the pump or the release of the pressure against the reamer arms or a piston connected to the reamer arms. Lastly, the reamer arms may be activated by temporarily connecting a motor drive rod to the reamer arms.

FIG. 18 shows the wired reamer 100 of FIG. 1 with controllers and actuators for changing the position of the reamer cutting structures. Wired reamer 100 further comprises controller-actuator assemblies 170 positioned between the reamer body 105 and the cutting structures 113. Each controller-actuator assembly 170 further comprise a controller and an actuator, where the controller, upon receiving a signal via the power and/or communications wiring 125, actuates the actuator to modify the position of the cutting structures 113, for example, to retract the cutting structures 113 to reduce the borehole diameter or to expand the cutting structures 113 to increase the borehole diameter.

Similarly, FIG. 19 shows the wired reamer 100 of FIG. 2 with controller and actuators for changing the position of the reamer cutting structures. In this embodiment, the pathway 120 for the power and/or communications wiring 125 passes through the reamer body 105. Because the wiring 125 passes through the reamer body 105, rather than the reamer flowbore 110, a cross-over between the controller-acutator assemblies 170 and the wiring 125 is not necessary.

As with previously described embodiments, power and/or communications need not be contiguous through a reamer, as they are depicted in FIGS. 18 and 19. Instead, power or communications may be provided through the reamer. Also, power and/or communications need not pass through the reamer, as depicted in FIGS. 18 and 19, but instead may only be provided to the reamer or contained entirely within the reamer. Also, as with previously described embodiments, the wired reamer may be a fixed blade reamer, as depicted in FIGS. 18 and 19, an adjustable blade reamer, or another type of reamer.

In other embodiments of the wired reamer with controllers and actuators, the controllers may actuate the actuators upon receiving a signal that originates from a processor. As described above, a wired reamer with sensors and access to a processor via its through-tool communications is a "smart reamer". In some embodiments of a smart reamer, controllers and actuators may be positioned on the reamer, and the controllers may be actuated by a direct command originating from the processor.

The direct command may originate from the operator of the smart reamer. Alternatively, the direct command may be a signal or feedback generated by an algorithm developed as a function of measured data and stored on the processor. Sensors located on other downhole tools may measure data, in particular, data relating to the operational parameters of the reamer and the formation characteristics of the surrounding formation being drilled. The measured data may be transmitted to the processor for use as input to the algorithm. Upon receiving the measure data, the processor may then execute the algorithm to generate feedback based on the measured data. The feedback may be transmitted in the form of a signal to the smart reamer via its thru-tool communications. The signal may direct a controller on the smart reamer to actuate an actuator, causing the smart reamer to react in a desired manner.

FIG. 20 shows the smart reamer 100 of FIG. 15 with controllers and actuators for changing the position of the reamer cutting structures. Smart reamer 100 further comprises controller-actuator assemblies 170 positioned between the reamer body 105 and the cutting structures 113. Each controller-actuator assembly 170 further comprise a controller and an actuator, where the controller, upon receiving a signal from the processor 165 via the power and/or communications wiring 125, actuates the actuator to modify the position of the cutting structures 113, for example, to retract the cutting structures 113 to reduce the borehole diameter or to expand the cutting structures 113 to increase the borehole diameter.

Similarly, FIG. 21 shows the wired reamer 100 of FIG. 16 with controller and actuators for changing the position of the reamer cutting structures. In this embodiment, the pathway 120 for the power and/or communications wiring 125 passes through the reamer body 105. Because the wiring 125 passes through the reamer body 105, rather than the reamer flowbore 110, a cross-over between the controller-actuator assemblies 170 and the wiring 125 is not necessary.

As with previously described embodiments, power and/or communications need not be contiguous through a reamer, as they are depicted in FIGS. 20 and 21. Instead, power or communications may be provided through the reamer. Also, power and/or communications need not pass through the reamer, as depicted in FIGS. 20 and 21, but instead may only be provided to the reamer or contained entirely within the reamer. Also, as with previously described embodiments, the wired reamer may be a fixed blade reamer, as depicted in FIGS. 20 and 21, an adjustable blade reamer, or another type of reamer. In embodiments of the smart reamer having communications through or to the reamer, the processor may be located at the surface, on another downhole tool, or on the reamer itself. In embodiments of the smart reamer having communications contained within the reamer, the processor is necessarily located on the reamer itself.

As yet another alternative, the direct command may be a signal or feedback generated by an algorithm developed as a function of data measured by sensors located on the smart reamer. In these embodiments, control of the smart reamer components is actuated in response to sensor data in a closed loop fashion. The components may be such devices as adjustable stabilization pads (located before and after the reamer blades), subs to control excessive torque applied to the reamer cutters, axial force applied to the reamer cutters or control of the tool rpm. Sensors monitor conditions of the reamer such as, for example, the vibration, torque on bit, weight on bit, formation characteristics, andrpm and a controller and actuator may activate the appropriate stabilizer or sub to control (limit or regulate) the forces on the tool. For example, the controller and actuator may extend or retract the stabilizer pad to minimize the vibration of the tool. As another example, the controller and actuator may permit a clutch to allow the string to spin, or a spring sub to temporarily absorb the high torque, in the situations where the reamer experiences high torque or rpm. As yet another example, the controller and actuator may cause a sub to extend or retract in order to modify the weight on the reamer cutters. As still another example, in response to data from an imaging device on a reamer arm indicating the reamer cutters are not cutting the formation wall, the controller and actuator may cause the reamer arm to apply more pressure on the surrounding formation at the cutters.

FIG. 22 shows the smart reamer 100 of FIG. 20, wherein the data measured by the sensors 140 is used as input to an algorithm stored and executed by the processor 165 to generate feedback or a signal. The signal is subsequently transmitted to the controller-actuator assemblies 170 of the smart reamer 100, directing the controller-actuator assemblies 170 to modify the position of the cutting structures 113. In this manner, the position of the cutting structures 113 is controlled, even optimized, in a closed-loop fashion.

Similarly, FIG. 23 shows the smart reamer 100 of FIG. 21, also operating in a closed-loop fashion to control the position of the cutting structures 113. In this embodiment, the pathway 120 for the power and/or communications wiring 125 passes through the reamer body 105. Because the wiring 125 passes through the reamer body 105, rather than the reamer flowbore 110, a cross-over between the controller-actuator assemblies 170 and the wiring 125 is not necessary.

As with previously described embodiments, power and/or communications need not be contiguous through a reamer, as they are depicted in FIGS. 22 and 23. Instead, power or communications may be provided through the reamer. Also, power and/or communications need not pass through the reamer, as depicted in FIGS. 22 and 23, but instead may only be provided to the reamer or contained entirely within the reamer. Also, as with previously described embodiments, the wired reamer may be a fixed blade reamer, as depicted in FIGS. 22 and 23, an adjustable blade reamer, or another type of reamer. In embodiments of the smart reamer having communications through or to the reamer, the processor may be located at the surface, on another downhole tool, or on the reamer itself. In embodiments of the smart reamer having communications contained within the reamer, the processor is necessarily located on the reamer itself.

While preferred embodiments have been shown and described, modifications thereof can be made by one skilled in the art without departing from the scope or teachings herein. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the system and apparatus are possible and are within the scope of the invention. For example, the relative dimensions of various parts, the materials from which the various parts are made, and other parameters can be varied. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims.

CLAIMS

What is claimed is:

1. A reamer for use on a downhole drillstring, comprising:
a reamer body comprising an uphole end and a downhole end;
a pathway extending from the uphole end to the downhole end of the reamer body;
wiring located within the pathway for transmitting at least one of power or communications downhole of the reamer, wherein the wiring extends from the uphole end to the downhole end of the reamer body; and
a sensor located within the reamer body, the sensor being connected with the wiring for transmitting data measured by the sensor through the wiring.

2. The reamer of claim 1, wherein the reamer body comprises a flowbore extending through the reamer body from the uphole end to the downhole end, and wherein the pathway extends through the flowbore.

3. The reamer of claim 2, further comprising a feed through assembly disposed within the flowbore, the feed through assembly surrounding at least a portion of the wiring.

4. The reamer of claim 1, wherein the reamer body further comprises a wall surrounding a flowbore extending through the reamer body and wherein the pathway extends through the wall.

5. The reamer of claim 1, wherein the sensor is selected from the group consisting of: a vibration sensor, a weight-on-bit sensor, a torque-on-bit sensor, a temperature sensor, a pressure-while-drilling sensor, a resistivity sensor, a nuclear sensor, an acoustic sensor, a nuclear magnetic resonance sensor, and a formation evaluation sensor.

6. The reamer of claim 1, wherein the reamer body further comprises a cutting structure and wherein a location of the sensor is selected from the group consisting of: above the cutting structure, below the cutting structure, and on the cutting structure.

7. The reamer of claim 1, further comprising the sensor being wirelessly connected with the wiring.

8. The reamer of claim 1, further comprising a processor connected with the wiring for receiving data from the sensor.

9. The reamer of claim 8, wherein the sensor is wirelessly connected with the wiring.

10. The reamer of claim 8, wherein the processor is positioned at a location, the location selected from the group consisting of: within the reamer body, at the surface, and on another downhole tool.

11. The reamer of claim 1, further comprising:

wherein the reamer is an adjustable blade reamer comprising adjustable blades;

an actuator operatively connected with the adjustable blades to adjust the position of the adjustable blades; and

a controller operatively connected with the actuator for controlling the position of the adjustable blades.

12. The reamer of claim 11, wherein the controller is configured to change the cutting diameter of the adjustable blades.

13. The reamer of claim 11, wherein the actuator is selected from the group consisting of: an electric actuator, a mechanical actuator, and a hydraulic actuator.

14. The reamer of claim 11, further comprising a processor connected with the controller for transmitting a signal to the controller, the signal directing the controller to actuate the actuator.

15. The reamer of claim 14, wherein the processor is positioned at a location, the location selected from the group consisting of: within the reamer body, at the surface, and on another downhole tool.

16. The reamer of claim 11, further comprising a processor being connected with the wiring for receiving the data from the sensor and with the controller for transmitting a signal to the controller, the signal directing the controller to actuate the actuator.

17. The reamer of claim 16, wherein the controller is configured to change the cutting diameter of the adjustable blades.

18. The reamer of claim 16, wherein the actuator is selected from the group consisting of: an electric actuator, a mechanical actuator, and a hydraulic actuator.

19. The reamer of claim 16, wherein the processor is positioned at a location, the location selected from the group consisting of: within the reamer body, at the surface, and on another downhole tool.

20. The reamer of claim 16, wherein the processor generates the signal as a function of the data received from the sensor.

21. A reamer for use on a downhole drillstring, comprising:

a reamer body comprising a pathway extending through at least a portion of the reamer body;

wiring located within the pathway for transmitting at least one of power or communications to or from the reamer;

a sensor located within the reamer body, the sensor being connected with the wiring for transmitting data measured by the sensor through the wiring; and

a processor located within the reamer body and connected with the wiring for receiving the data from the sensor.

22. The reamer of claim 21, wherein the reamer body pathway comprises a portion of a flowbore extending through the reamer body.

23. The reamer of claim 22, further comprising a feed through assembly, the feed through assembly surrounding at least a portion of the wiring.

24. The reamer of claim 21, wherein the reamer body further comprises a wall surrounding a flowbore extending through the reamer body and wherein the pathway extends through a portion of the wall.

25. The reamer of claim 21, wherein the reamer body further comprises a cutting structure and wherein a location of the sensor is selected from the group consisting of: above the cutting structure, below the cutting structure, and on the cutting structure.

26. The reamer of claim 21, further comprising the sensor being wirelessly connected with the wiring.

27. The reamer of claim 21, further comprising:

wherein the reamer is an adjustable blade reamer comprising adjustable blades;

an actuator operatively connected with the adjustable blades to adjust the position of the adjustable blades; and

a controller operatively connected with the actuator for controlling the position of the adjustable blades.

28. The reamer of claim 27, wherein the controller is configured to change the cutting diameter of the adjustable blades.

29. The reamer of claim 27, wherein the actuator is selected from the group consisting of: an electric actuator, a mechanical actuator, and a hydraulic actuator.

30. The reamer of claim 27 wherein the processor is connected with the controller for transmitting a signal to the controller, the signal directing the controller to actuate the actuator.

31. The reamer of claim 30, wherein the controller is configured to change the cutting diameter of the adjustable blades.

32. The reamer of claim 30, wherein the actuator is selected from the group consisting of: an electric actuator, a mechanical actuator, and a hydraulic actuator.

33. The reamer of claim 30, wherein the processor generates the signal as a function of the data received from the sensor.

34. A reamer for use on a downhole drillstring, comprising:

a reamer body comprising a pathway enclosed within the reamer body;

wiring located within the pathway for transmitting at least one of power or communications;

a sensor located within the reamer body, the sensor being connected with the wiring for transmitting data measured by the sensor through the wiring; and

a processor located within the reamer body and connected with the wiring for receiving the data from the sensor.

35. The reamer of claim 34, wherein the reamer body pathway comprises a flowbore extending through the reamer body.

36. The reamer of claim 35, further comprising a feed through assembly, the feed through assembly surrounding at least a portion of the wiring.

37. The reamer of claim 34, wherein the reamer body further comprises a wall surrounding a flowbore extending through the reamer body and wherein the pathway extends through the wall.

38. The reamer of claim 34, wherein the reamer body further comprises a cutting structure and wherein a location of the sensor is selected from the group consisting of: above the cutting structure, below the cutting structure, and on the cutting structure.

39. The reamer of claim 34, wherein the sensor is wirelessly connected with the wiring.

40. The reamer of claim 34, further comprising:

wherein the reamer is an adjustable blade reamer comprising adjustable blades;

an actuator operatively connected with the adjustable blades to adjust the position of the adjustable blades; and a controller operatively connected with the actuator for controlling the position of the adjustable blades.

41. The reamer of claim 40, wherein the controller is configured to change the cutting diameter of the adjustable blades.

42. The reamer of claim 40, wherein the actuator is selected from the group consisting of: an electric actuator, a mechanical actuator, and a hydraulic actuator.

43. The reamer of claim 40, wherein the processor is connected with the controller for transmitting a signal to the controller, the signal directing the controller to actuate the actuator.

44. The reamer of claim 43, wherein the processor generates the signal as a function of the data received from the sensor.

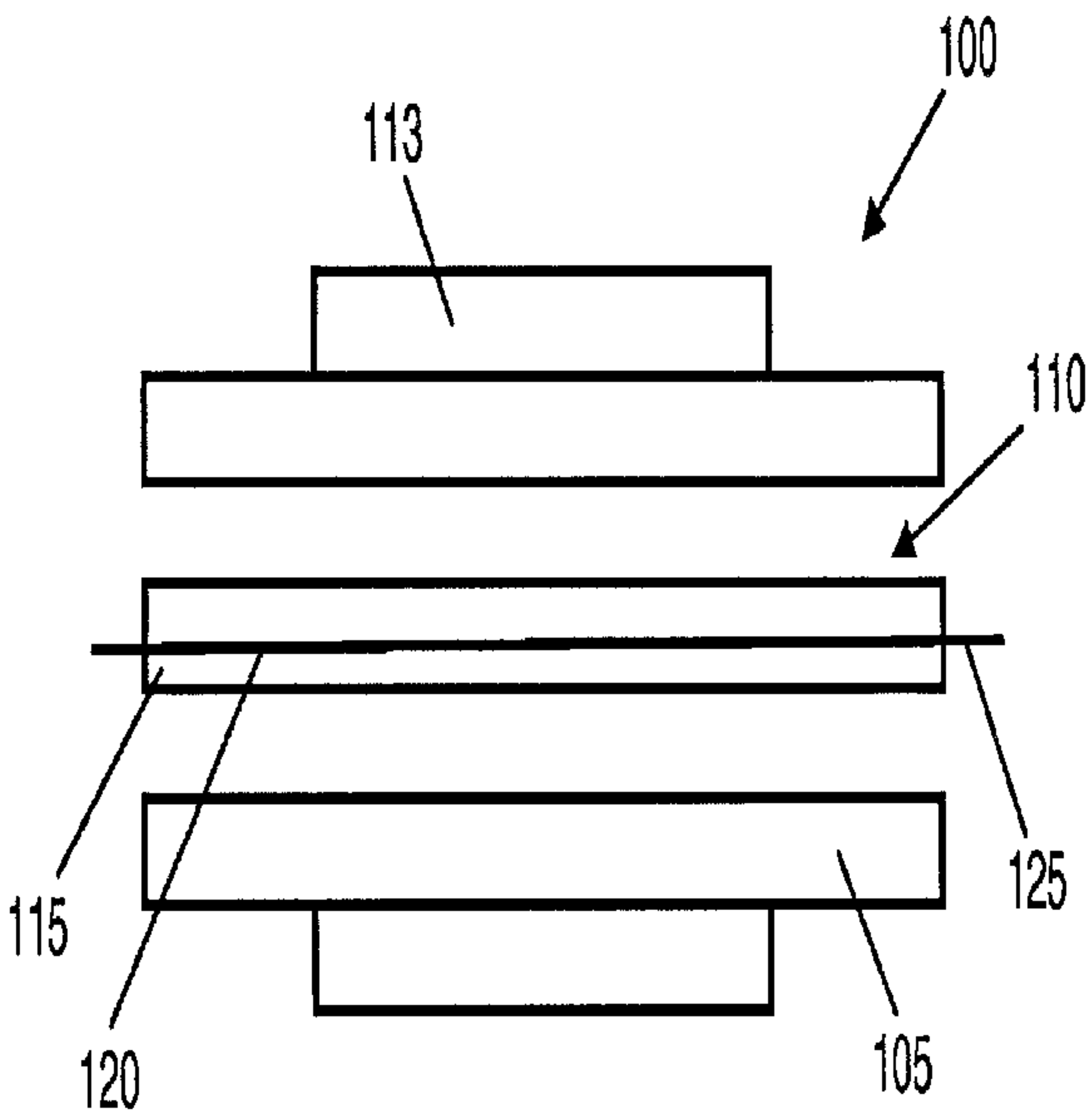


FIG. 1

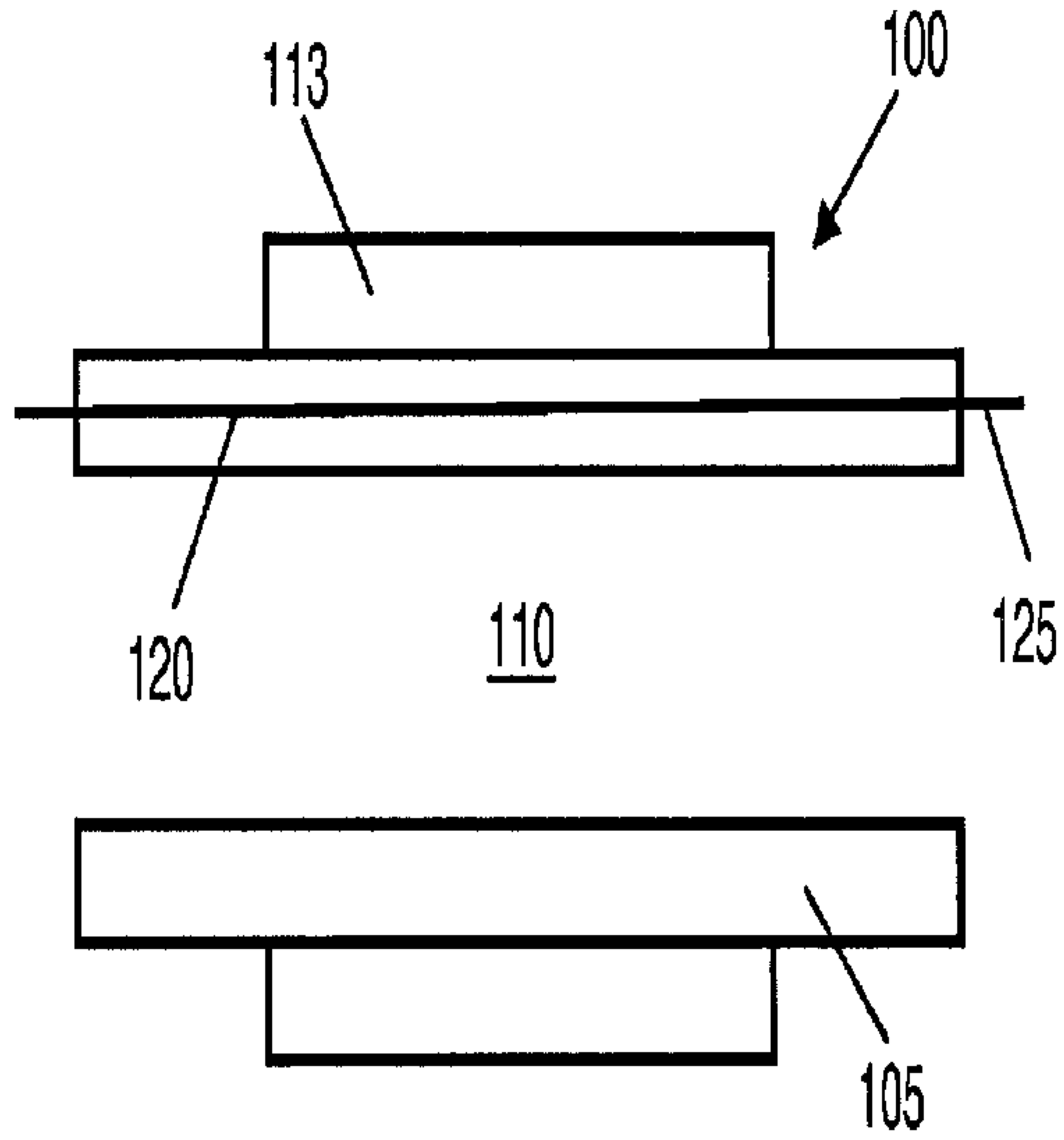


FIG. 2

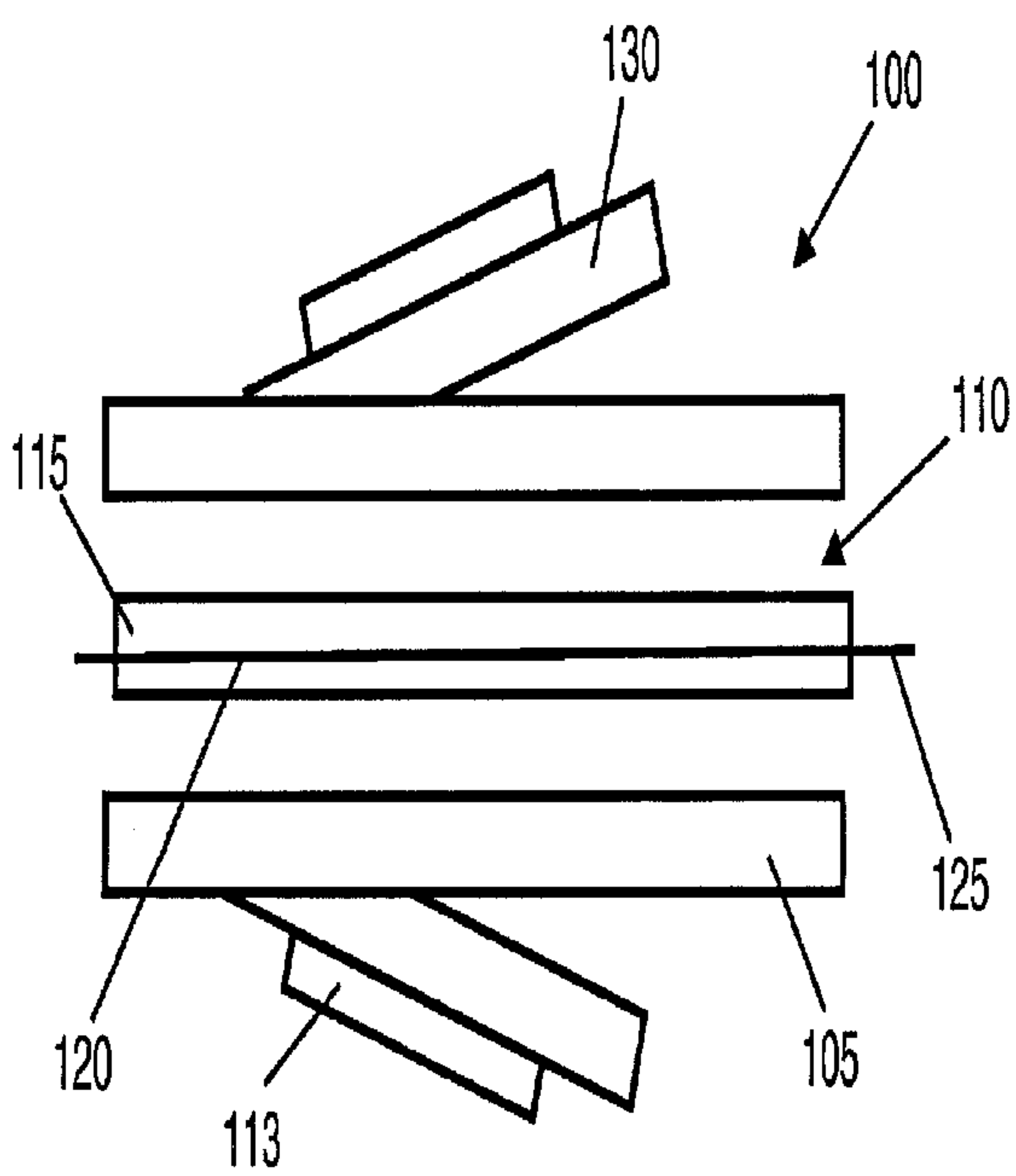


FIG. 3

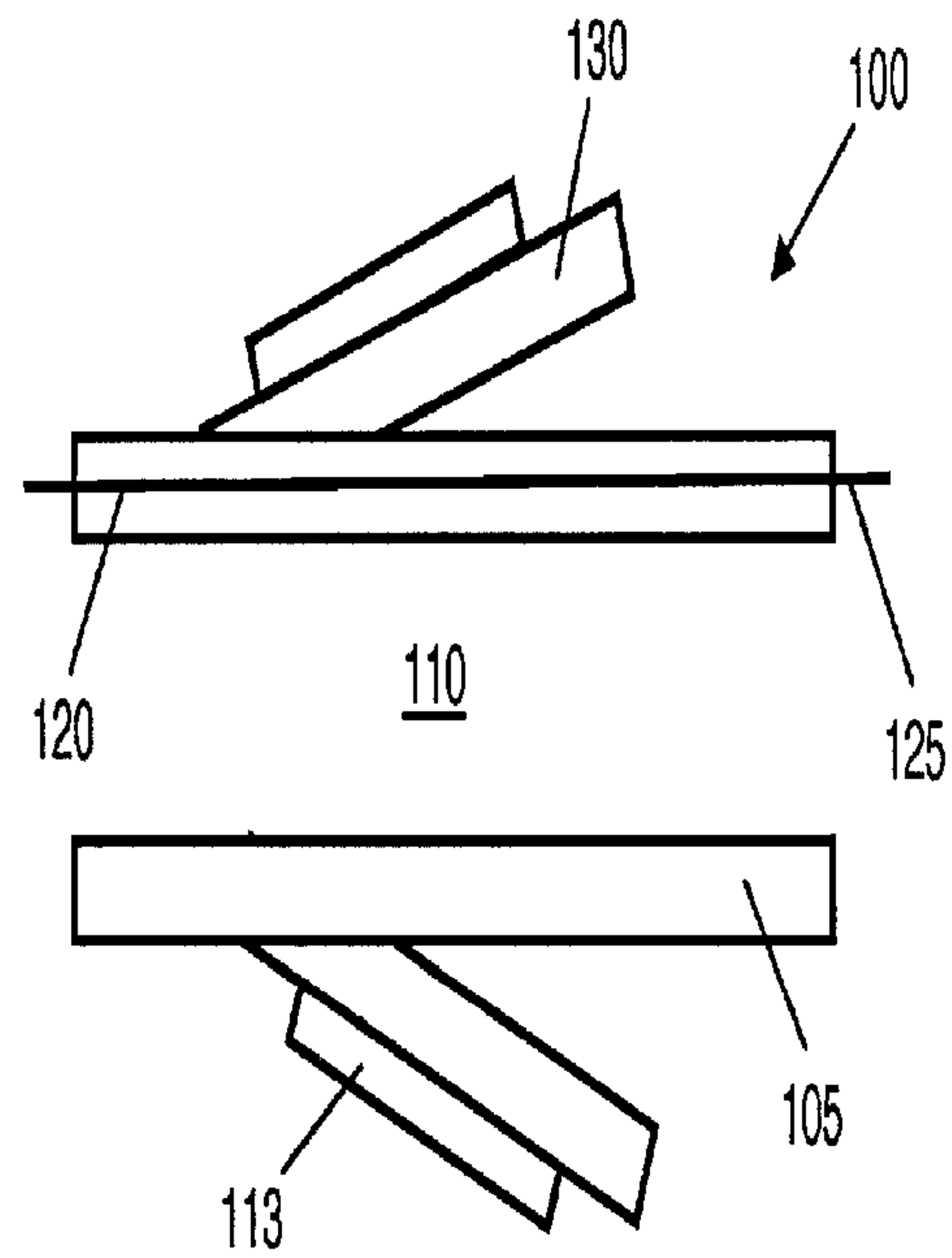


FIG. 4

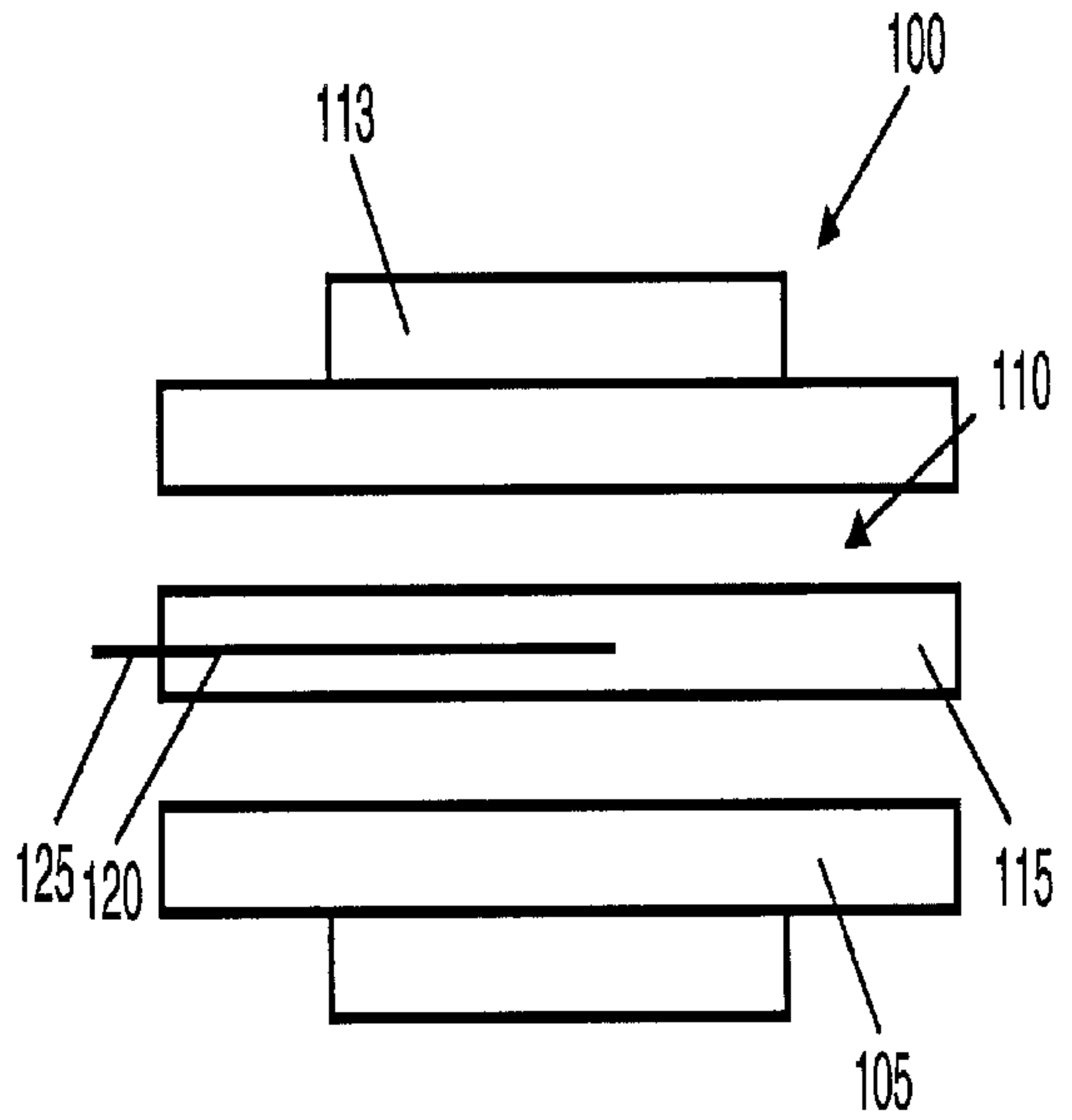


FIG. 5

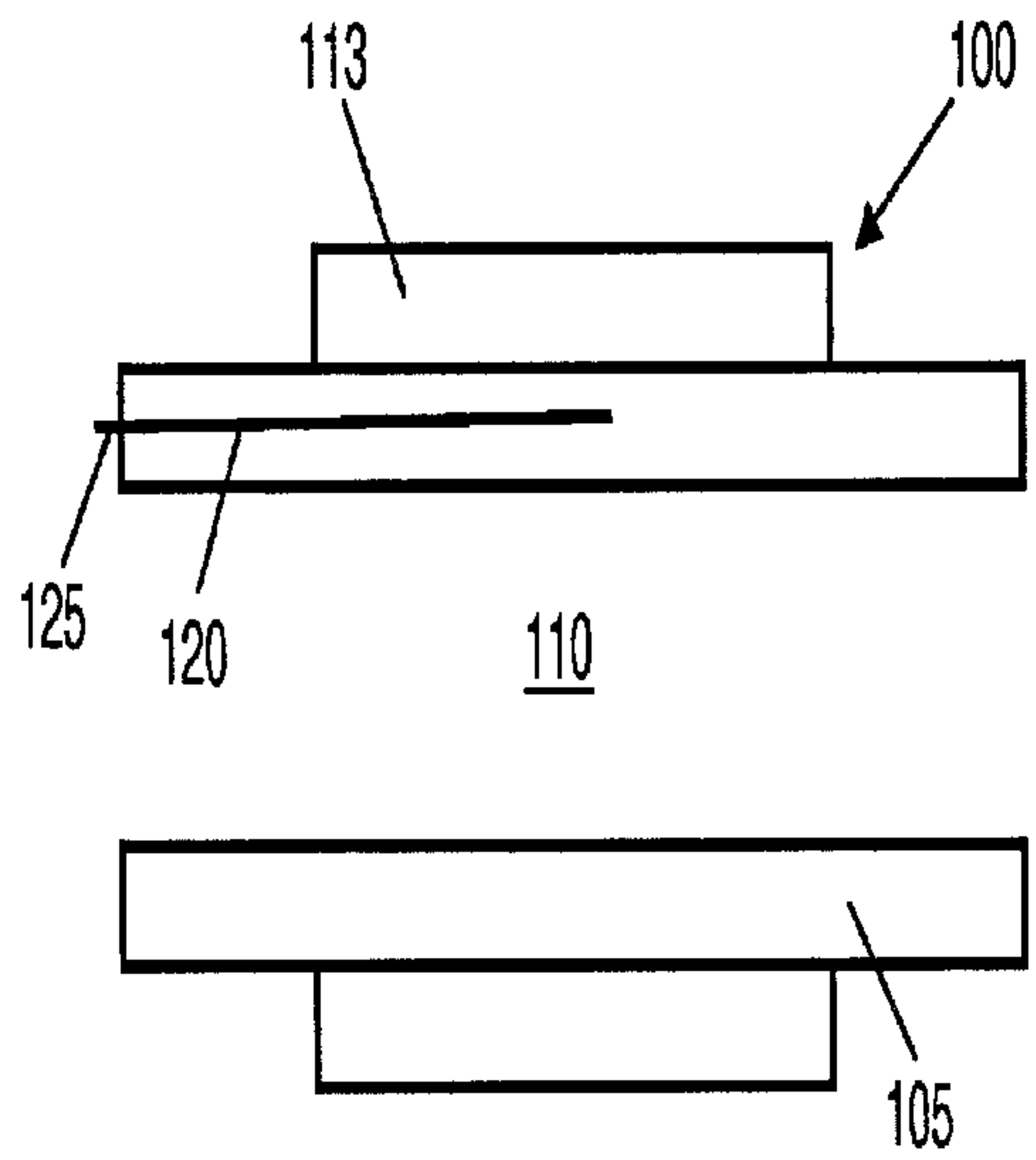


FIG. 6

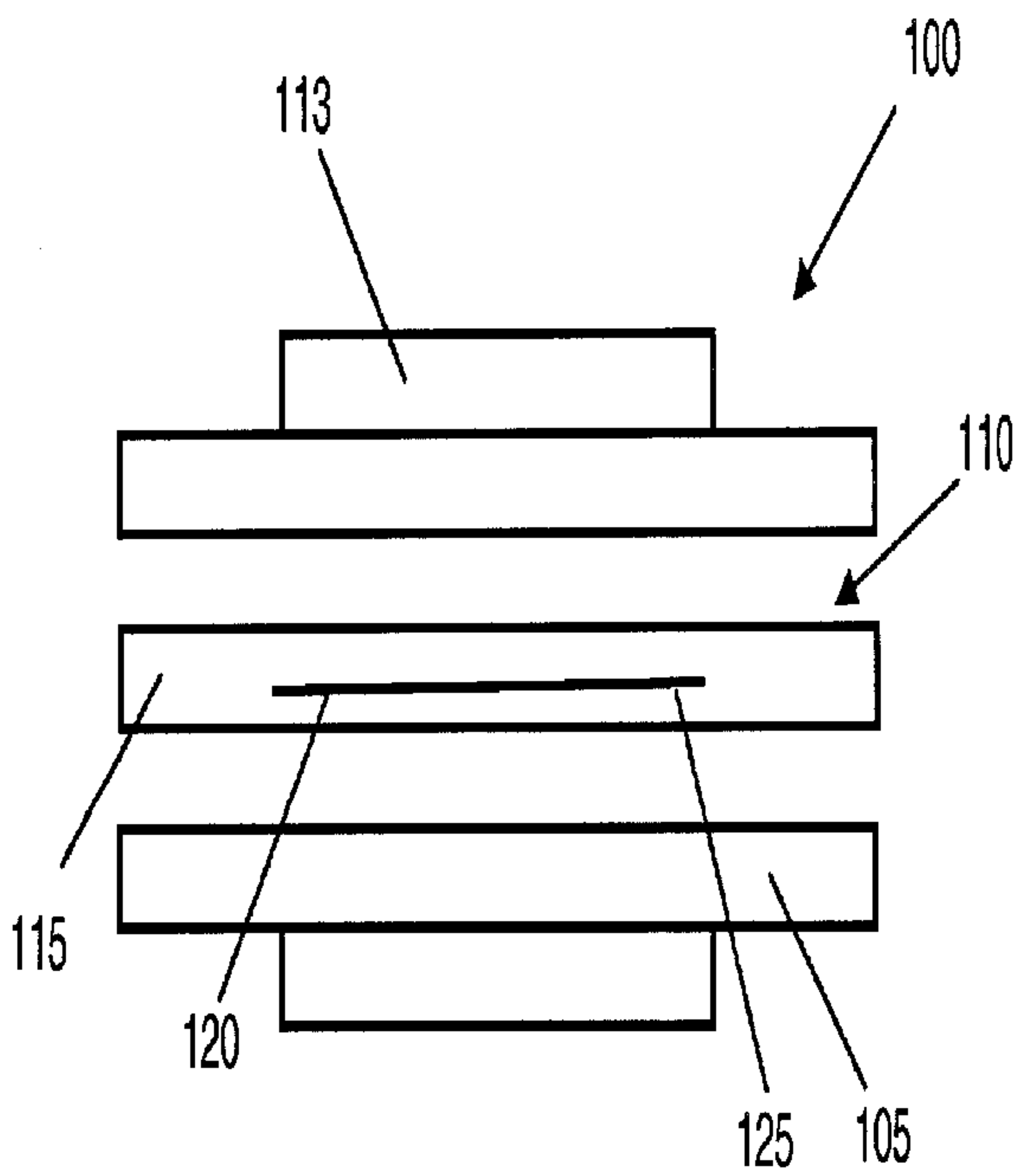


FIG. 7

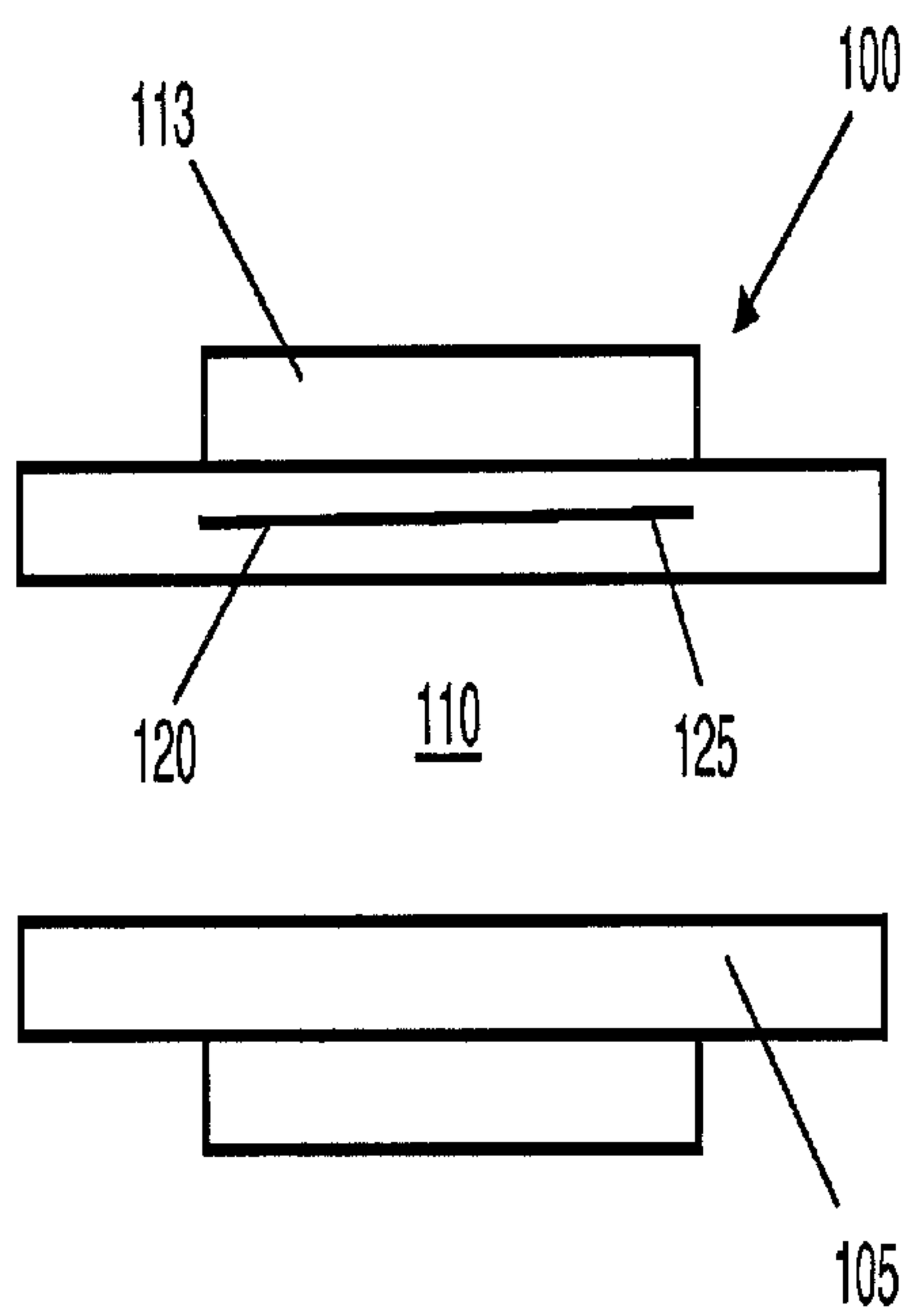


FIG. 8

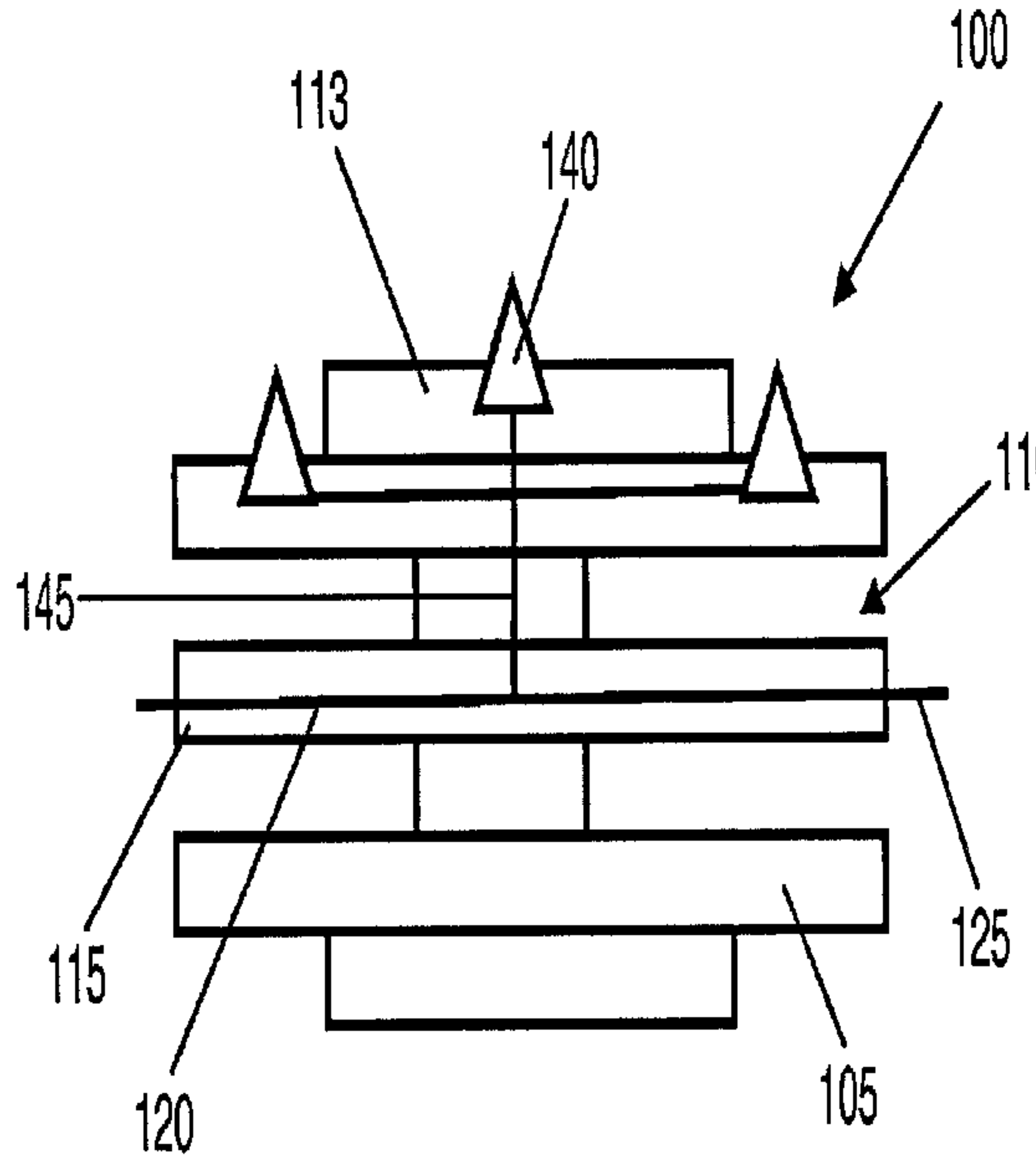


FIG. 9

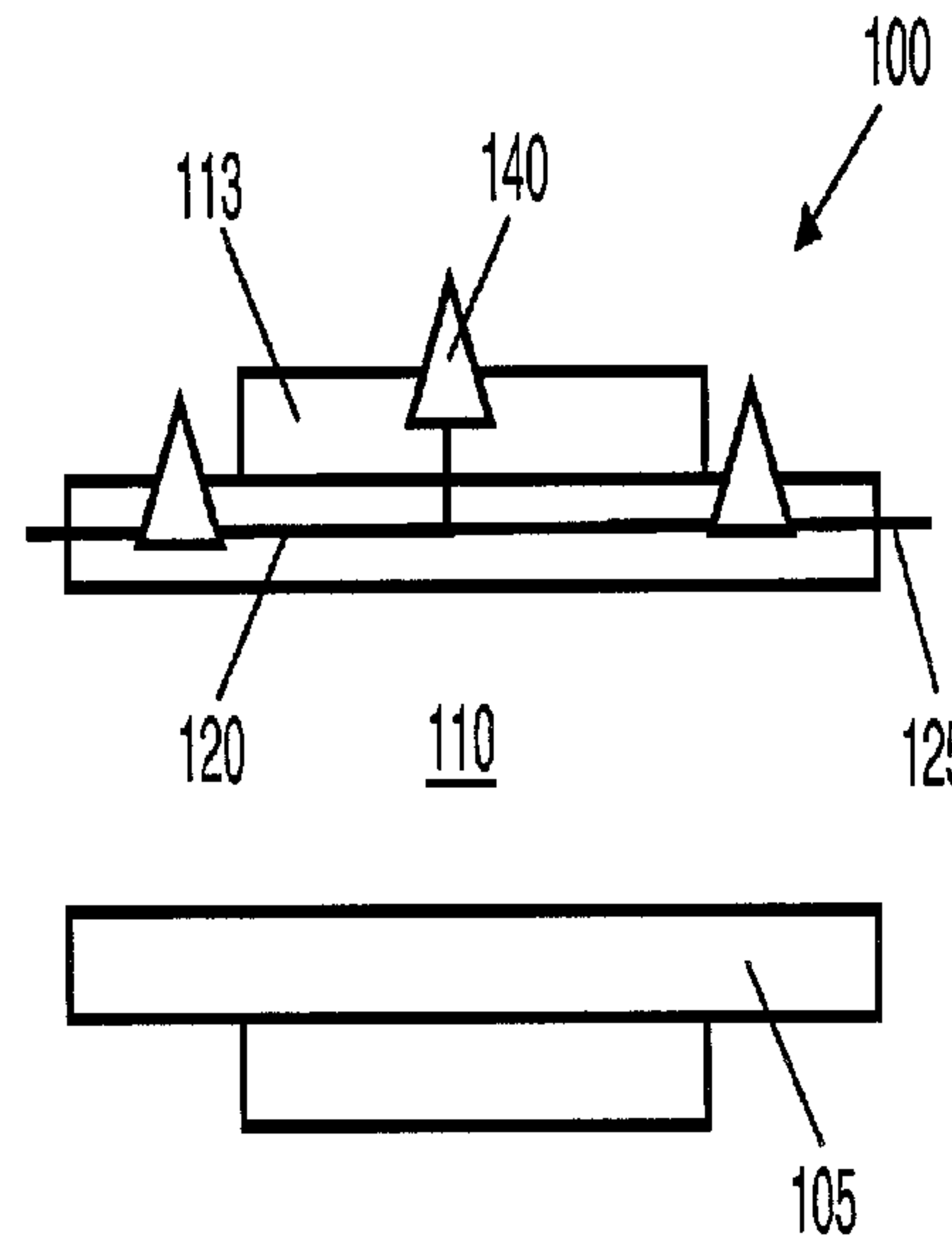


FIG. 10

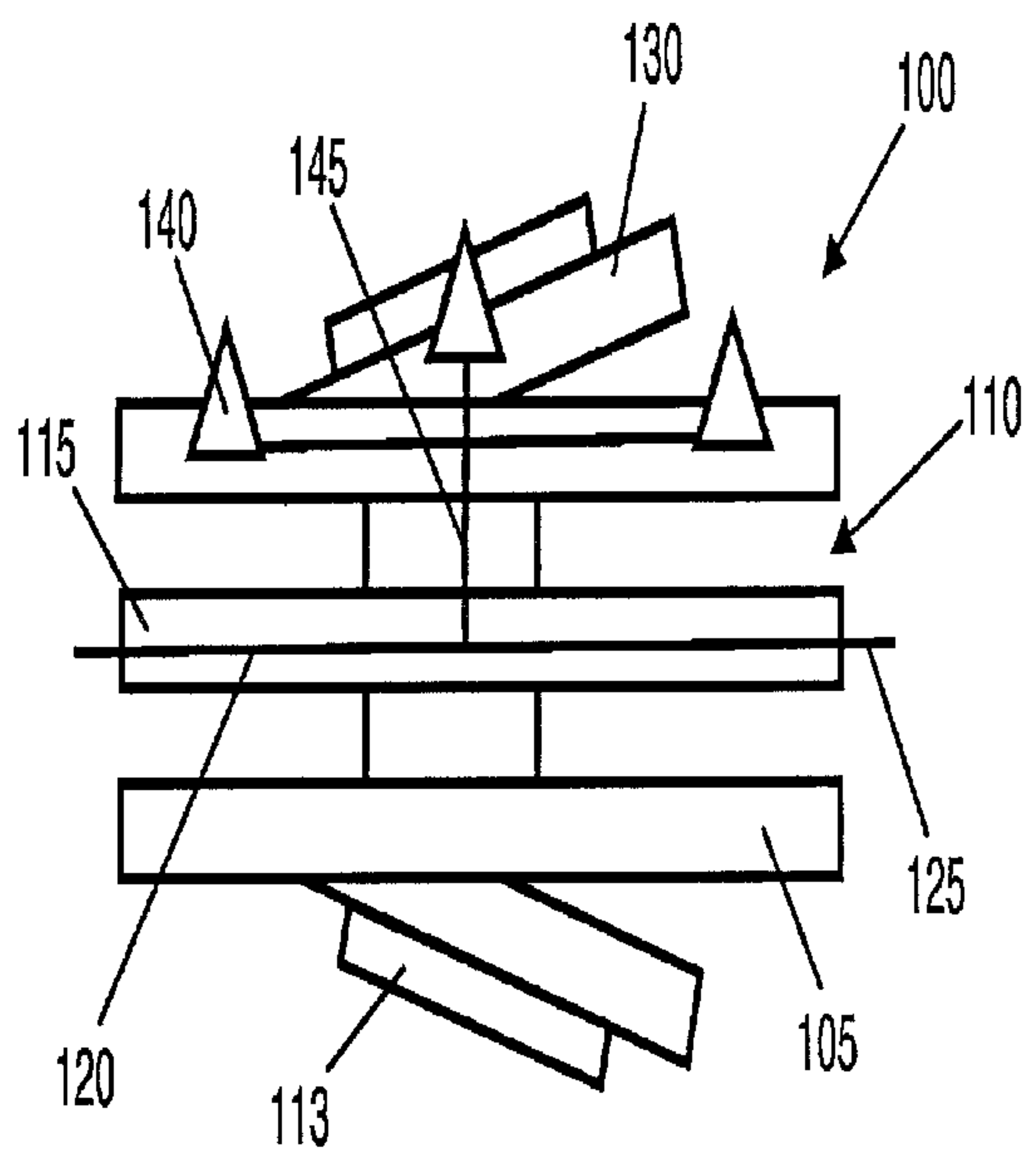


FIG. 11

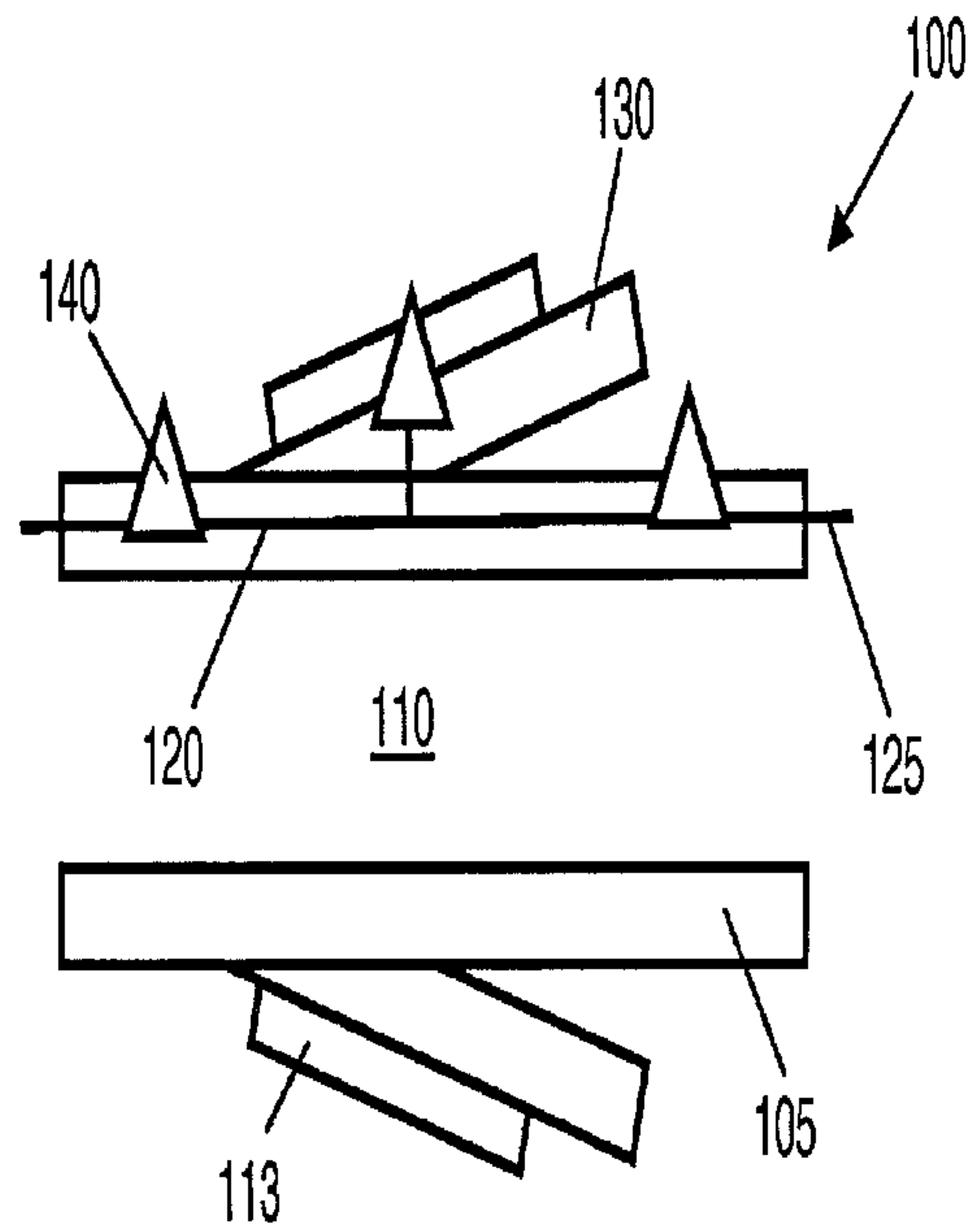


FIG. 12

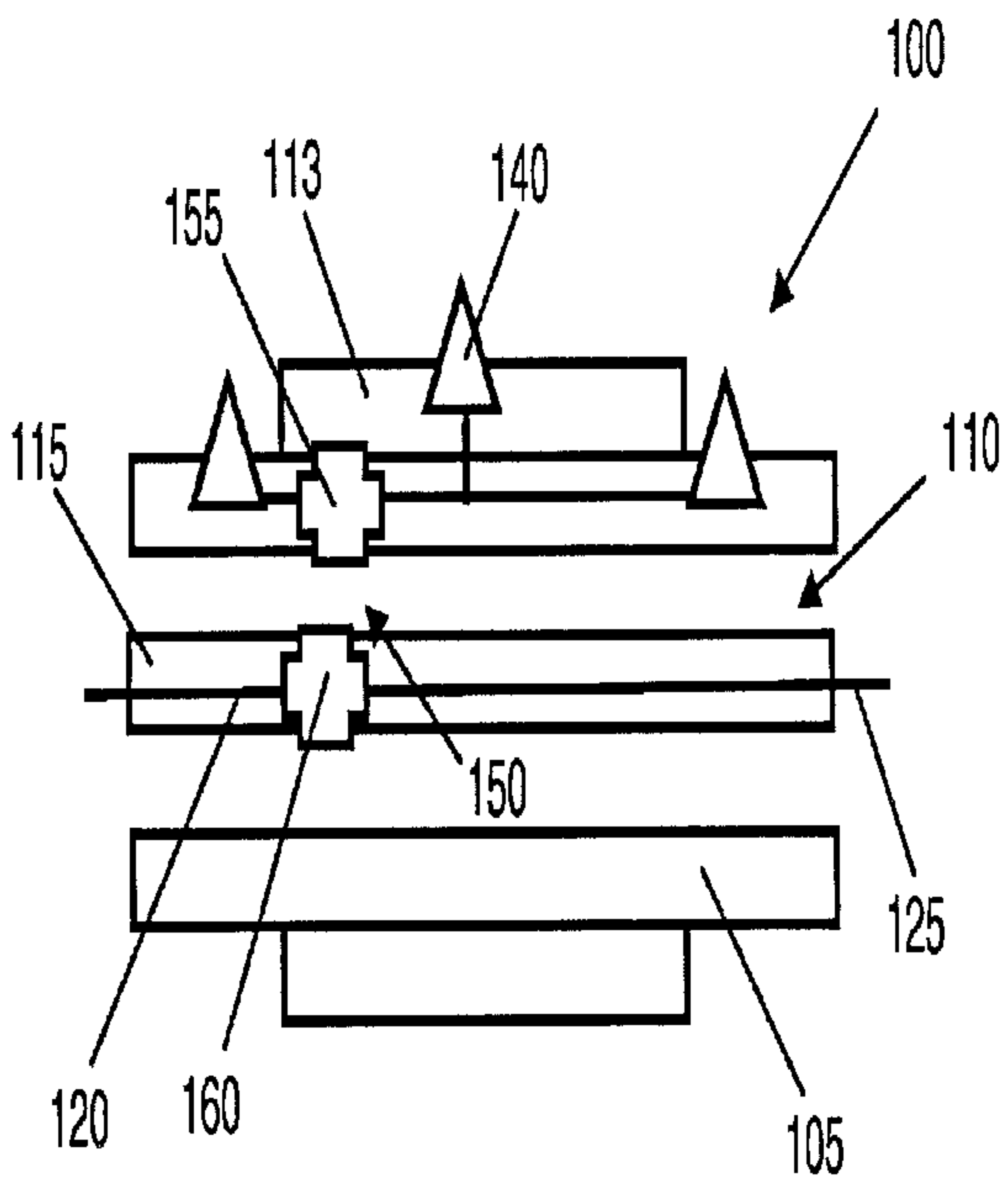

100
113
140
155
115
110
150
125
120
160
105

FIG. 13

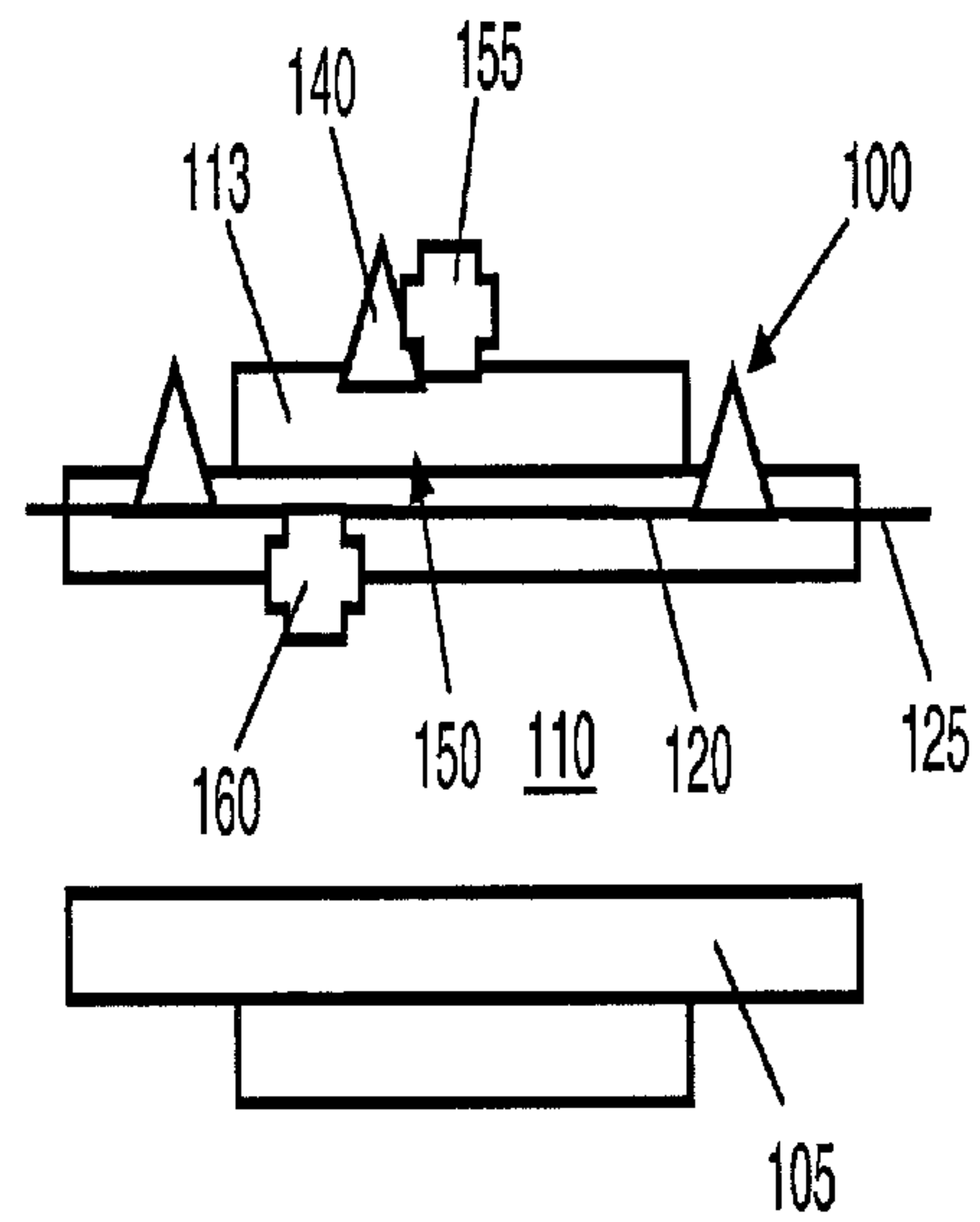

140
155
113
100
160
150
110
120
125
105

FIG. 14

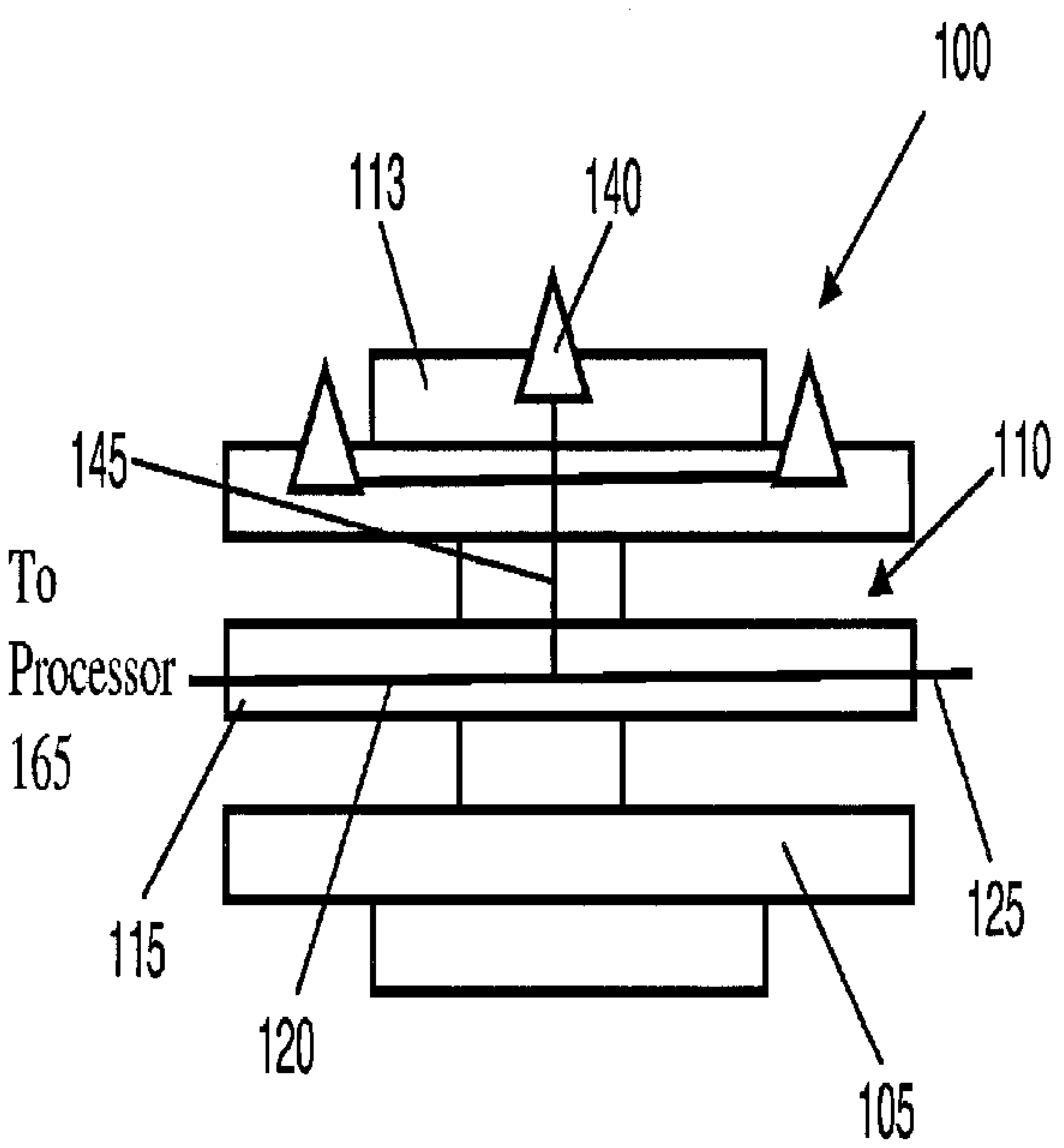


FIG. 15

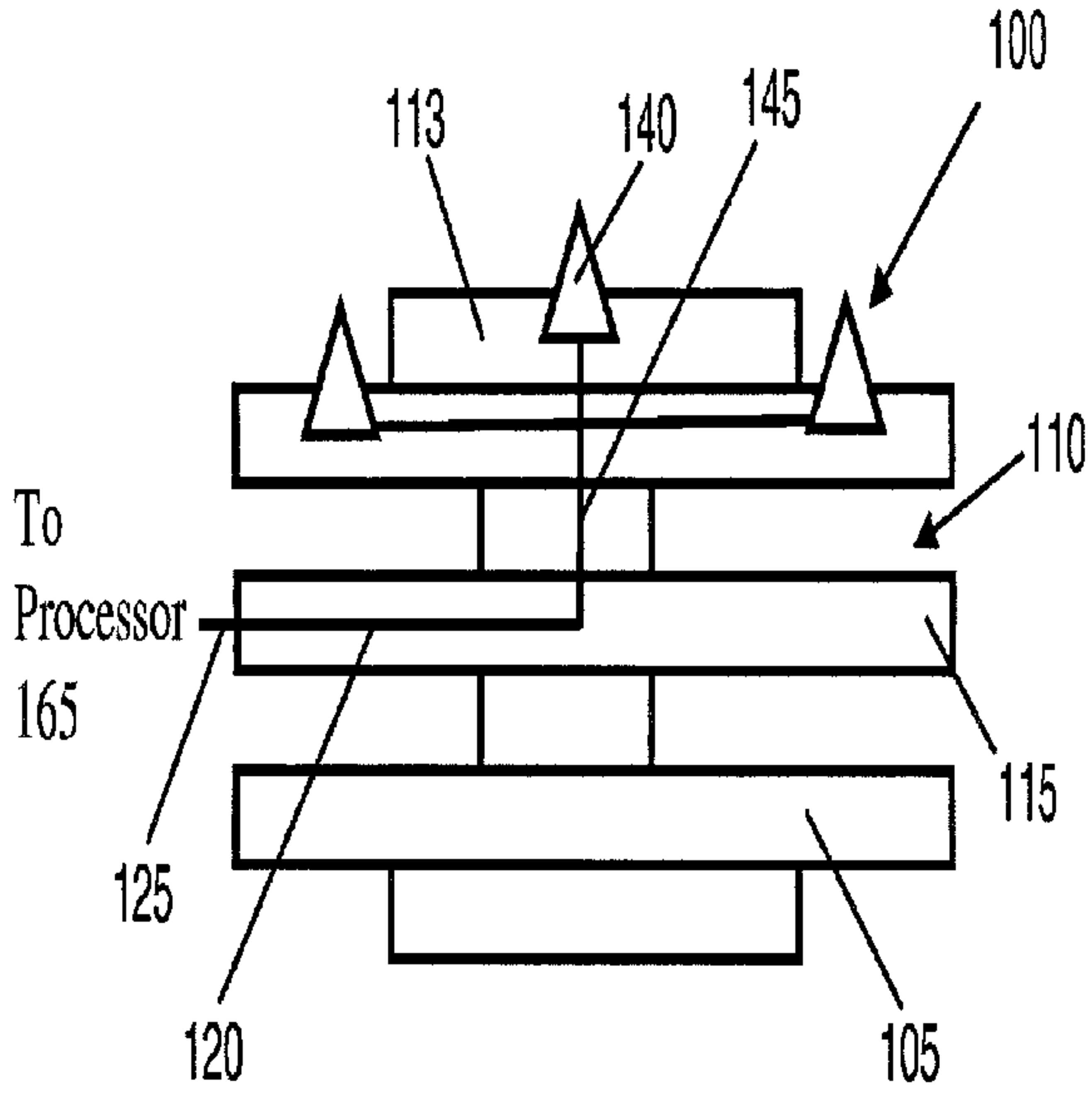


FIG. 16

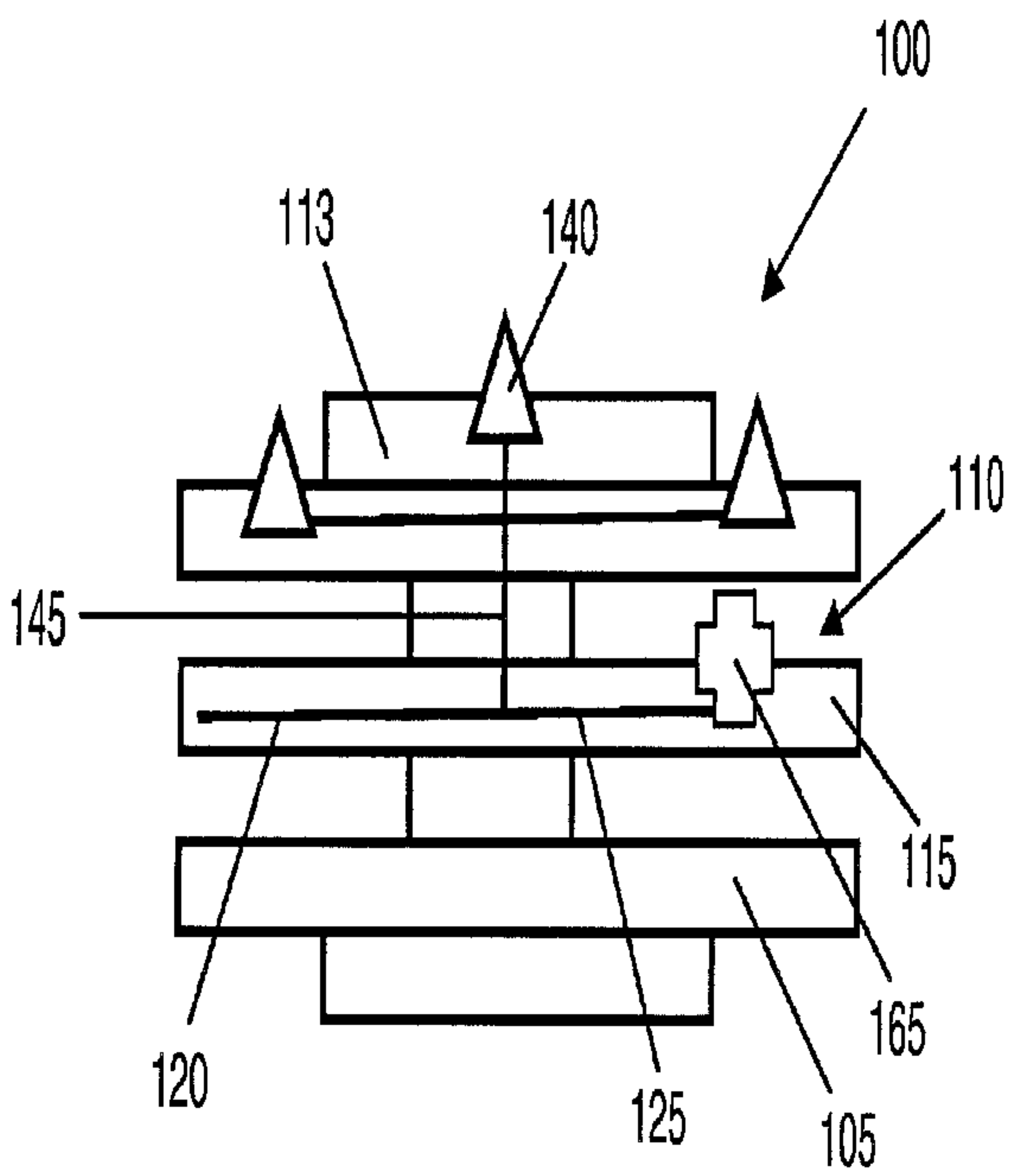


FIG. 17

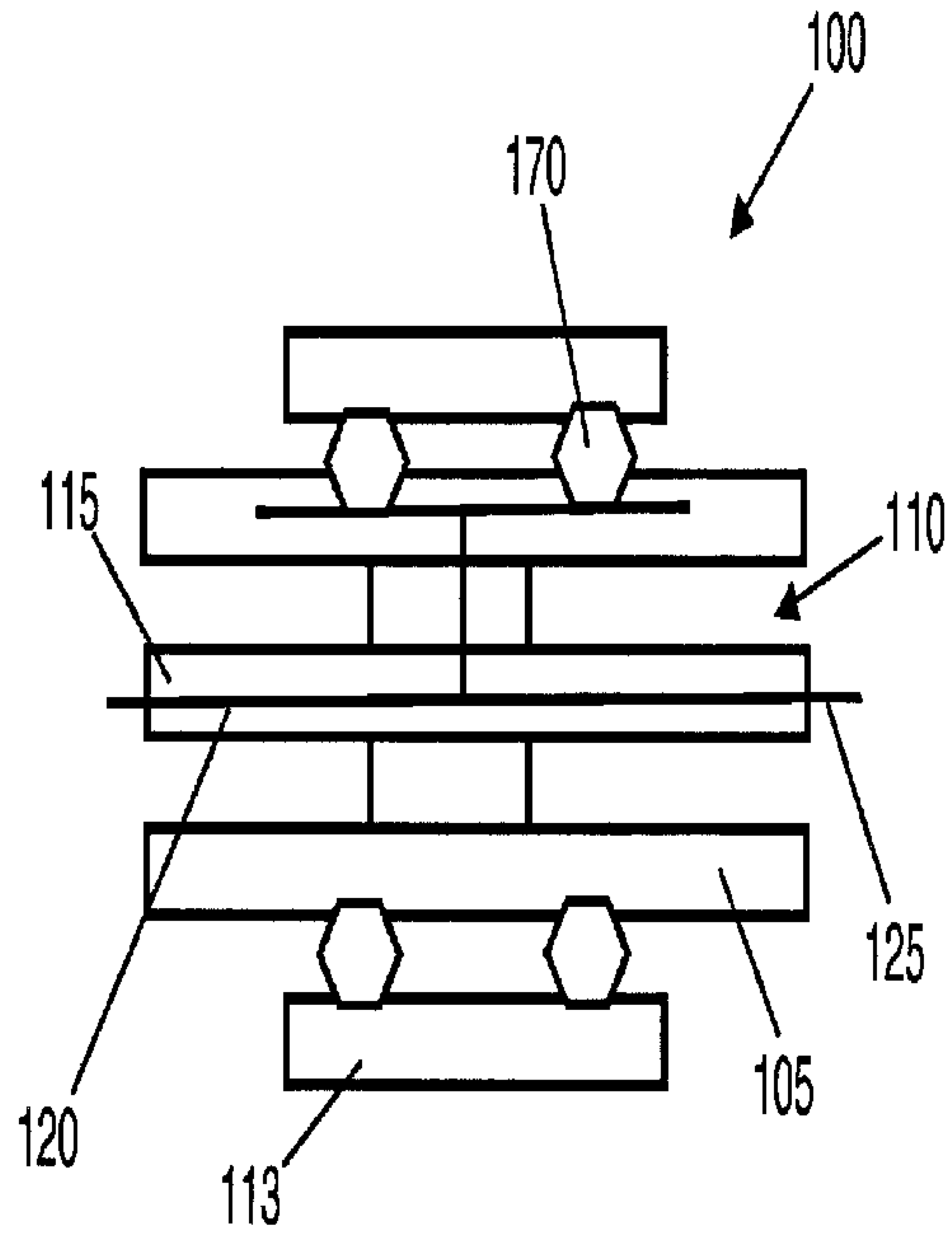


FIG. 18

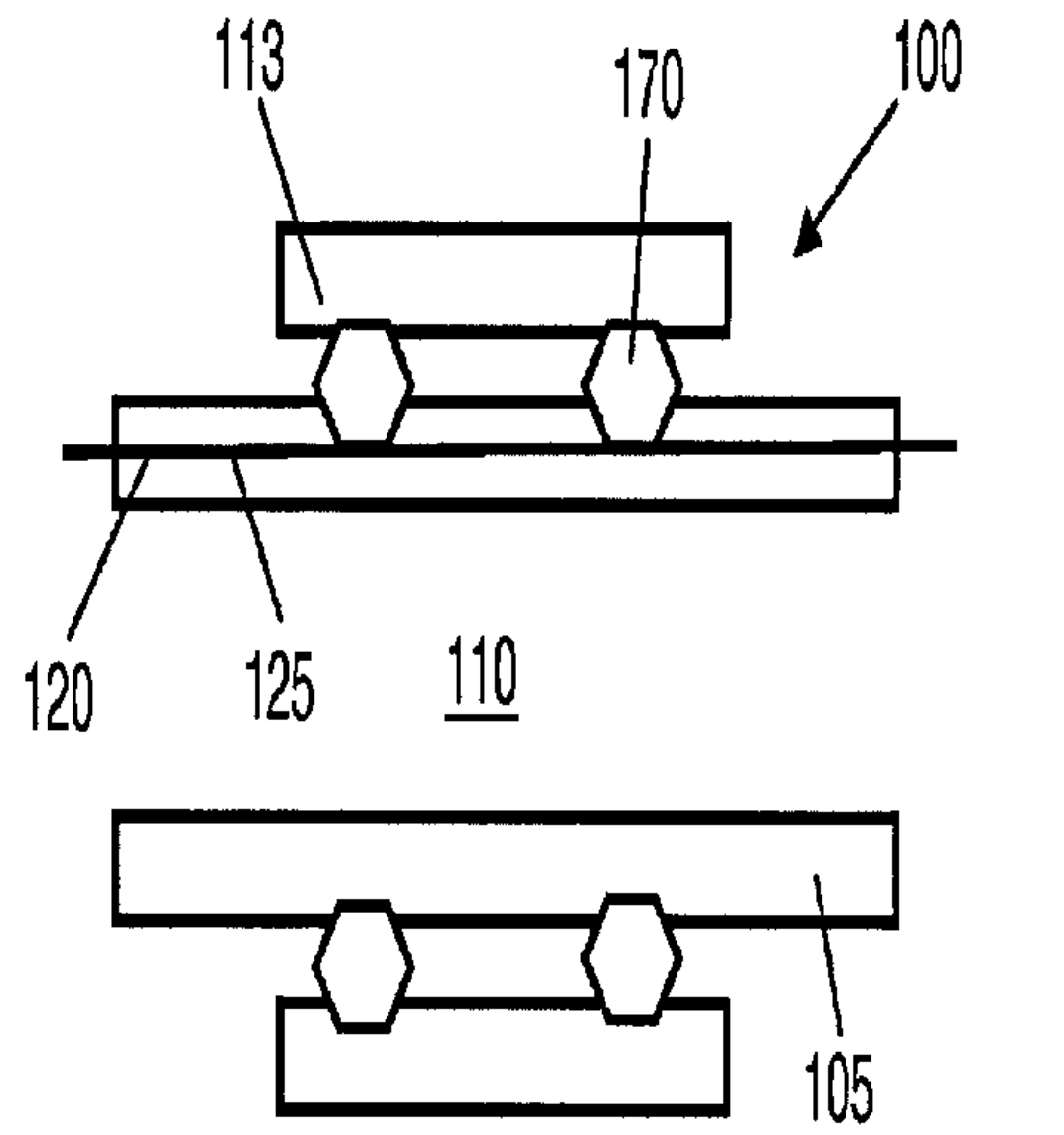


FIG. 19

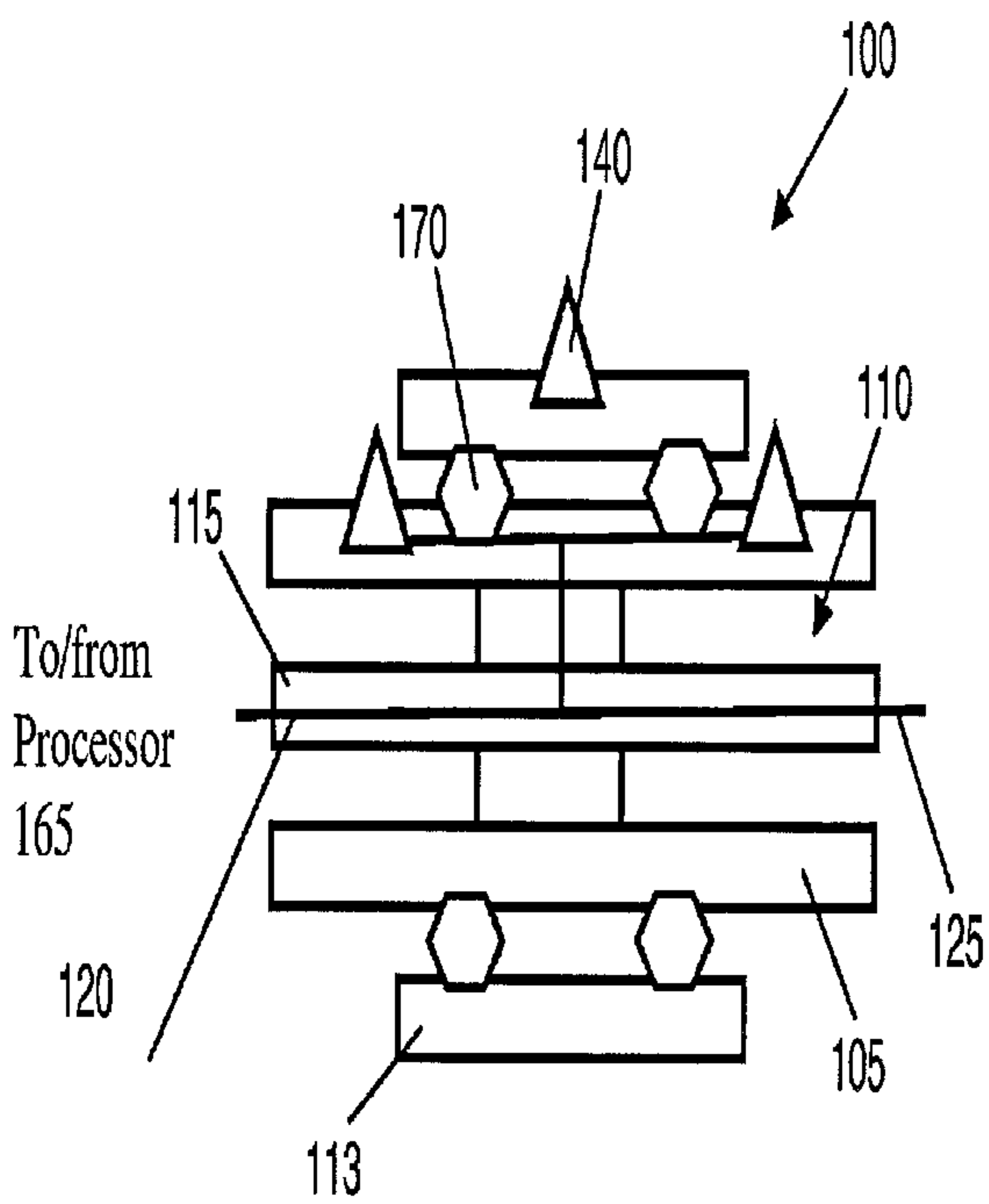


FIG. 20

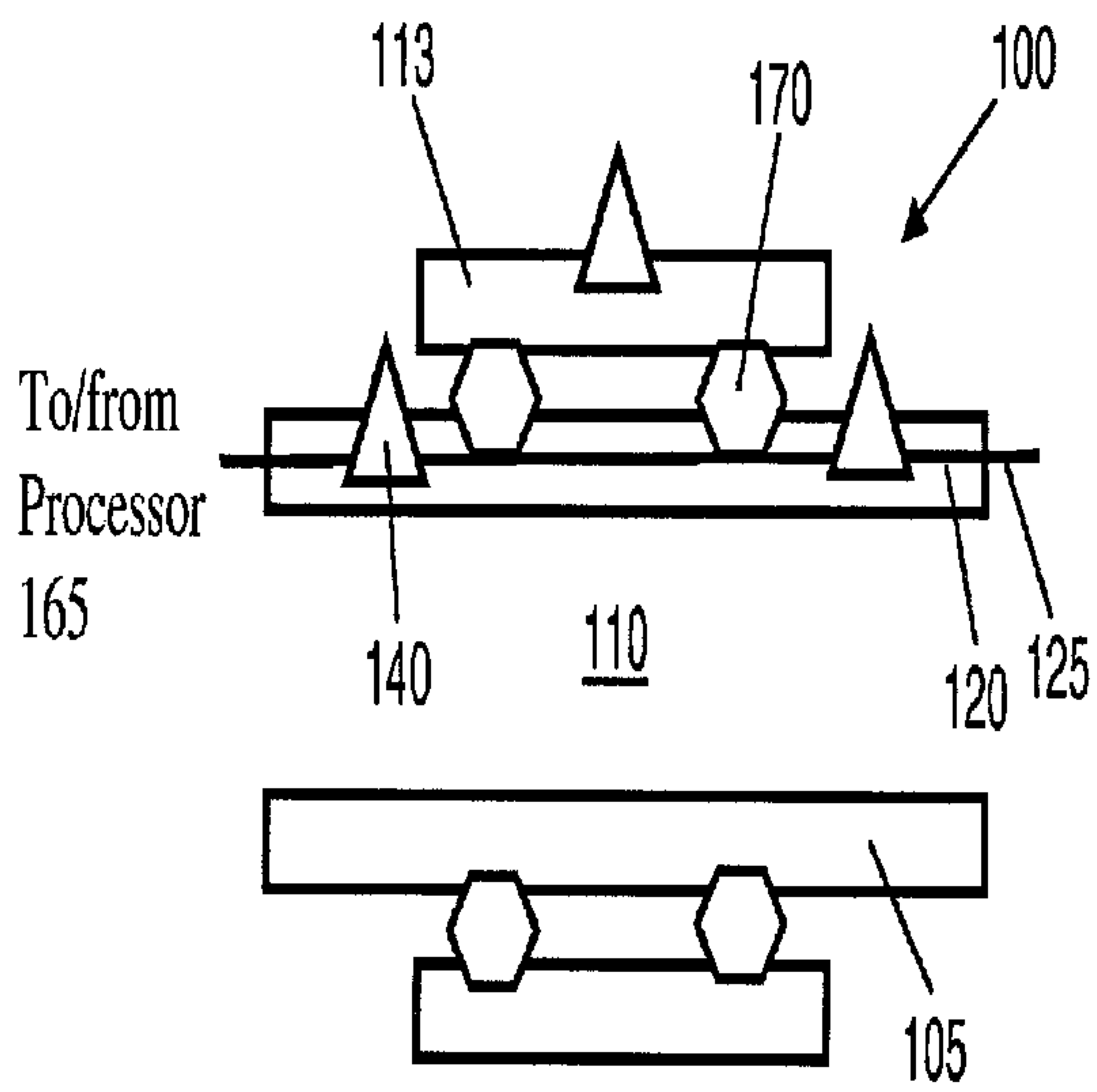


FIG. 21

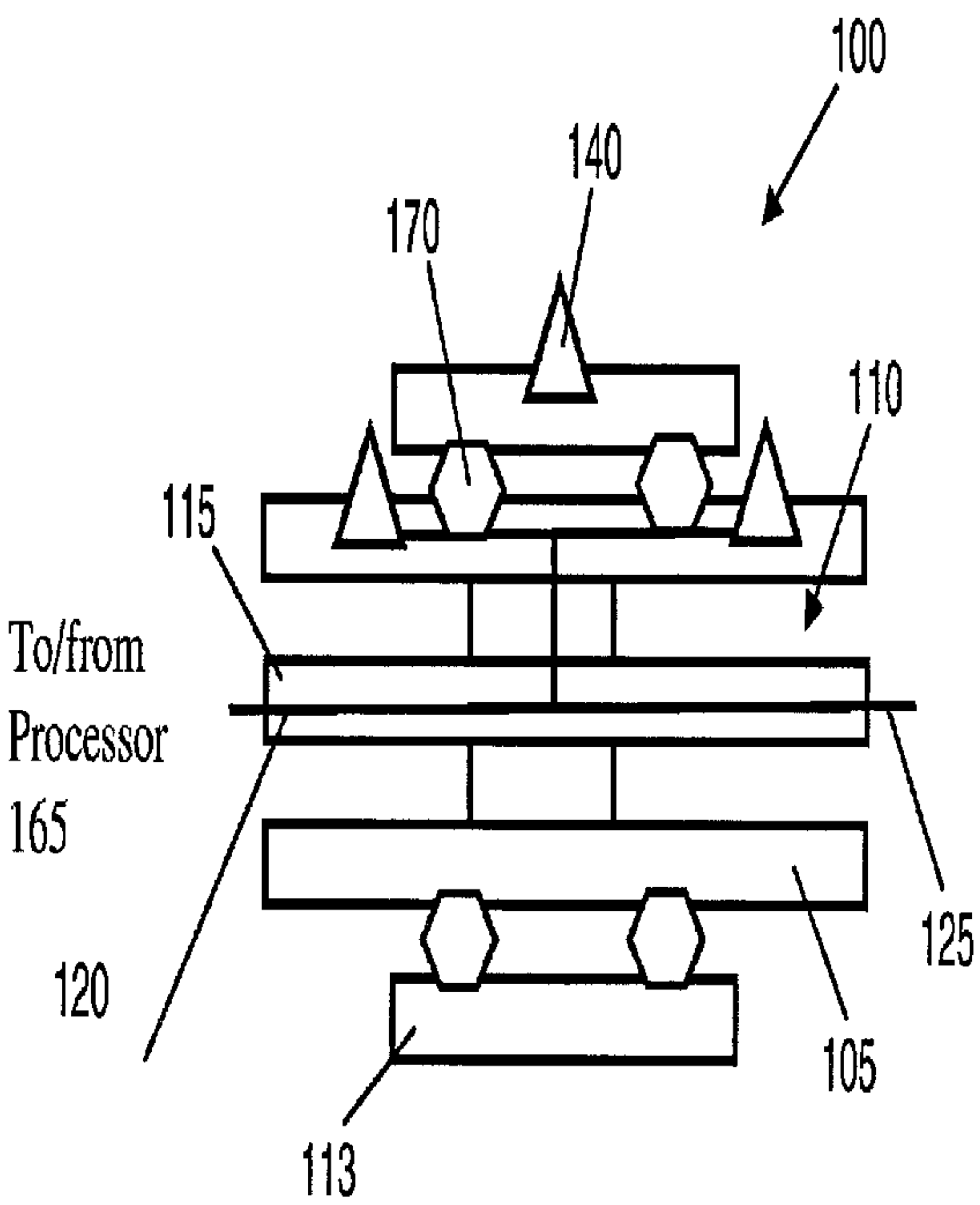

100
140
170
110
115
To/from
Processor
165
120
125
105
113

FIG. 22

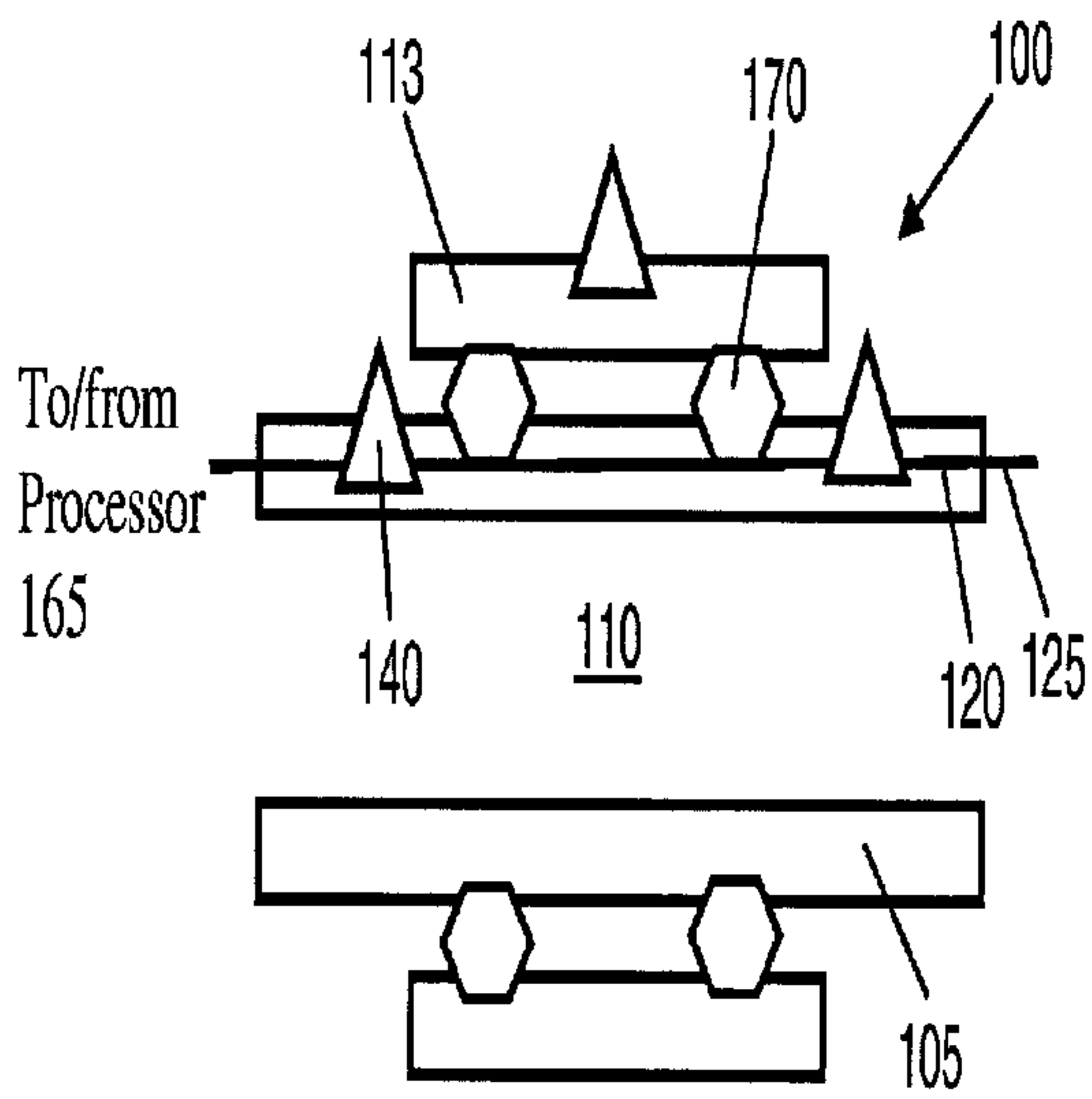
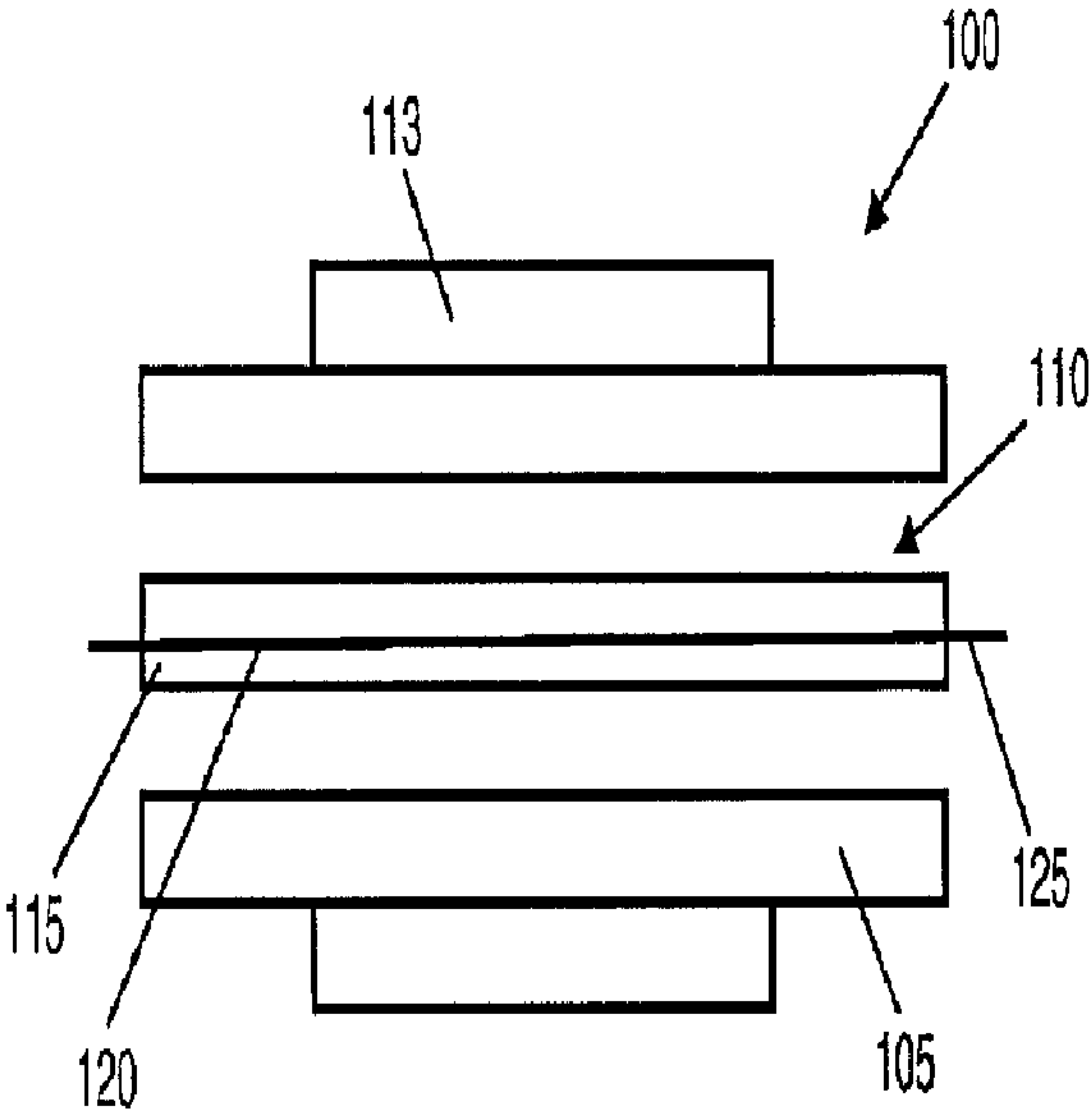

113
170
100
To/from
Processor
165
140
110
120
125
105

FIG. 23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