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- (73) Patenthaver: **Weatherford Technology Holdings, LLC, 2000 St. James Place, Houston Texas 77056, USA**
- (72) Opfinder: **KNIGHT, Matthew David, Heathbank, Newmachar, Aberdeenshire AB21 7PP, Storbritannien**
- (74) Fuldmægtig i Danmark: **MURGITROYD & COMPANY, Scotland House, 165-169 Scotland Street, Glasgow G5 8PL,
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DESCRIPTION

[0001] The present invention relates to a method and apparatus for controlling a downhole tool in a well, and relates to a method of transmitting instructions to control a downhole tool in a well and more specifically but not exclusively results in multiplexing between the outputs of at least two downhole sensors, one of which is preferably an RFID tag reader and another of which is preferably a downhole fluid pressure sensor.

[0002] International PCT Publication No WO2009/050517 to Petrowell Limited of Aberdeen discloses use of a downhole Radio Frequency Identification (RFID) sensor responsive to Radio Frequency (RF) tags which are flowed past the RFID sensor in fluid or pressure sensors responsive to pressure signals respectively, wherein the system operates:-

1. a) in RF mode (using the aforementioned RF tags) when there is circulation of fluid in the well (particularly fluid being pumped downhole through the throughbore of a tubing string); or
2. b) a pressure pulsing mode wherein the pressure sensor detects pulses sent through downhole fluid when the throughbore of the tubing string is closed.

[0003] It is desirable to increase the versatility of remote communication with a downhole tool while conserving power.

[0004] US 2014/182845 A1, WO 2011/097063 A2, WO 2012/082248 A1, WO 2009/050517 A2, WO 2009/109788 A1, WO 02/04988 A1, WO 2009/143409 A2 and WO 2014/127489 A1 are useful for understanding the present invention.

Summary of the Invention

[0005] According to a first aspect there is provided a method of controlling a downhole tool in a well with a downhole processing device according to claim 1.

[0006] According to a second aspect there is provided a downhole processing apparatus according to claim 11.

[0007] Optionally, the first and second timing operations determine when the stored data received from the RFID tag reader and downhole fluid pressure pulse sensor is checked.

[0008] Optionally, the downhole processing device is triggered to check the data storage device when the first timing operation underflows or resets from zero to a pre-determined value that the timing operation will then count down to zero from. Optionally, the pre-

determined value for the first timing operation is a relatively short predetermined value (relative to the second timing operation).

[0009] Optionally, the downhole processing device is triggered to check the data storage device when the second timing operation underflows or resets from zero to a pre-determined value that the timing operation will then count down to zero from.

[0010] Optionally, the first and second pre-determined values are stored in a memory storage device and are provided to the respective first and second timing operations upon initiation of the downhole processing device.

[0011] Optionally, the first timing operation comprises a timed event including a repeating countdown from the pre-determined time value to zero wherein said timed event is repeated at least once.

[0012] Optionally, the second timing operation comprises a timed event including a repeating countdown from the pre-determined time value to zero wherein said timed event is repeated at least once.

[0013] Further optionally, the point at which said timed event resets from zero to the said pre-determined time value comprises an underflow trigger which triggers the checking of the stored data received from the respective RFID tag reader and downhole fluid pressure pulse sensor.

[0014] Optionally, the downhole processing device stores data if instructed to do so during predetermined time intervals determined by the first and second timing operations. Yet further optionally, the downhole processing device is pre-programmed to recognise flags represented by said stored data and/or trends within the stored data and is adapted to act upon said flags or said trends to for example instruct a downhole tool to actuate.

[0015] Embodiments of the present invention have the advantage that they effectively enable multiplexing between the outputs of an RFID tag reader and a downhole fluid pressure pulse sensor.

[0016] Optionally, the first and second timing operations comprise selectively actuable respective first and second interrupt service routines.

[0017] The various aspects of the present invention can be practiced alone or in combination with one or more of the other aspects, as will be appreciated by those skilled in the relevant arts. The various aspects of the invention can optionally be provided in combination with one or more of the optional features of the other aspects of the invention. Also, optional features described in relation to one embodiment can typically be combined alone or together with other features in different embodiments of the invention.

Brief Description of the drawings

[0018] Embodiments of the invention will now be described with reference to the accompanying Figures (Figs.), in which:-

Fig. 1 is a schematic view of a horizontal well prior to initiation of production;

Fig. 2 is a schematic view of a horizontal well in full production;

Fig. 3 is a schematic diagram of components that form part of a downhole apparatus according to the first aspect of the present invention;

Fig. 4 is a flow diagram showing a general overview of some of the steps of operation conducted by a Microprocessor Unit of the downhole apparatus of Fig. 3;

Fig. 5 is a flow diagram showing the steps of operation conducted by the Microprocessor Unit of the downhole device of Fig. 3 during Interrupt Service Routine (ISR) 1;

Fig. 6 is a flow diagram showing the steps of operation conducted by the Microprocessor Unit of the downhole device of Fig. 3 during ISR 2; and

Fig. 7 is a flow diagram showing the steps of operation conducted by the Microprocessor Unit of the downhole device of Fig. 3 during ISR 3.

Detailed Description of the Drawings

[0019] In the description that follows, like parts are marked throughout the specification and drawings with the same reference numerals, respectively. The drawings are not necessarily to scale. Certain features of the invention may be shown exaggerated in scale or in somewhat schematic form, and some details of conventional elements may not be shown in the interest of clarity and conciseness. The present invention is susceptible to embodiments of different forms. There are shown in the drawings, and herein will be described in detail, specific embodiments of the present invention with the understanding that the present disclosure is to be considered an exemplification of the principles of the invention, and is not intended to limit the invention to that illustrated and described herein. It is to be fully recognized that the different teachings of the embodiments discussed below may be employed separately or in any suitable combination to produce the desired results.

[0020] The following definitions will be followed in the specification. As used herein, the term "wellbore" refers to a wellbore or borehole being provided or drilled in a manner known to those skilled in the art. The wellbore may be 'open hole' or 'cased', being lined with a tubular string. Reference to up or down will be made for purposes of description with the terms "above", "up", "upward", "upper" or "upstream" meaning away from the bottom of the wellbore

along the longitudinal axis of a work string and "below", "down", "downward", "lower" or "downstream" meaning toward the bottom of the wellbore along the longitudinal axis of the work string. Similarly 'work string' refers to any tubular arrangement for conveying fluids and/or tools from a surface into a wellbore. In the present invention, production tubing is the preferred work string.

[0021] The various aspects of the present invention can be practiced alone or in combination with one or more of the other aspects, as will be appreciated by those skilled in the relevant arts. The various aspects of the invention can optionally be provided in combination with one or more of the optional features of the other aspects of the invention.

[0022] Various embodiments and aspects of the invention will now be described in detail with reference to the accompanying figures. Still other aspects, features, and advantages of the present invention are readily apparent from the entire description thereof, including the figures, which illustrates a number of exemplary embodiments and aspects and implementations. The invention is also capable of other and different embodiments and aspects, and its several details can be modified in various respects, all without departing from the scope of the present invention as defined by the claims.

[0023] Any discussion of documents, acts, materials, devices, articles and the like is included in the specification solely for the purpose of providing a context for the present invention. It is not suggested or represented that any or all of these matters formed part of the prior art base or were common general knowledge in the field relevant to the present invention.

[0024] Accordingly, the drawings and descriptions are to be regarded as illustrative in nature, and not as restrictive. Furthermore, the terminology and phraseology used herein is solely used for descriptive purposes and should not be construed as limiting in scope. Language such as "including", "comprising", "having", "containing" or "involving" and variations thereof, is intended to be broad and encompass the subject matter listed thereafter, equivalents and additional subject matter not recited, and is not intended to exclude other additives, components, integers or steps. Likewise, the term "comprising" is considered synonymous with the terms "including" or "containing" for applicable legal purposes.

[0025] All numerical values in this disclosure are understood as being modified by "about". All singular forms of elements, or any other components described herein including (without limitations) components of the embodiments of downhole control device 44 in accordance with the present invention to be described in detail subsequently are understood to include plural forms thereof and vice versa.

[0026] Figs. 1 and 2 show a well drilled into a formation 10. The well has a vertical portion 12, a horizontal portion 18, a heel 14 at the transition between the vertical portion 12 and the horizontal portion 18, and a toe 16 located at an end of the horizontal portion 18. The well is shown in Figs. 1 and 2 having tubing 42 such as production tubing 42 or work string 42 or wash pipe 42 inserted therein.

[0027] It should be noted that Figs. 1 and 2 are not to scale and that the horizontal portion 18 of the well may be many hundreds of metres or several kilometres long. However, it should also be noted that embodiments of the present invention to be described in detail subsequently are not limited to use only in horizontal wells but could be used in vertical wells or inclined wells that pass through the production zone at any angle.

[0028] Optionally, the production tubing 42 is formed from a plurality of individual pipe lengths that are interconnected and sealed to form continuous hollow tubing. The production tubing 42 can also incorporate other downhole devices and porting as appropriate. It should also be noted that embodiments of the present invention to be described in detail subsequently are not limited to use with production tubing 42 but could instead be used during the well completion process and particularly could be used when fracturing a well (also known as fracking or fracing/frac'ing) in which case the production tubing 42 shown in Fig. 1 would be replaced by work string or wash pipe 42 carrying one or more packers (not shown to isolate the section of the well to be frac'ed).

[0029] In Fig.1 as shown, in the horizontal portion 18 of the well, the production tubing 42 incorporates several downhole processing apparatus in accordance with the first aspect of the present invention in the form of downhole control devices 44 spaced at various points along the production tubing 42. Each control device 44 is located in close proximity to a respective port 26 which forms an aperture through the sidewall of the production tubing 42 and which can be opened or closed by a respective downhole tool 100 incorporating a moveable sleeve 100 as will be detailed subsequently but it should be noted that the moveable sleeve 100 and associated port 26 could be replaced by a different sort of downhole tool 100 (that may or may not be associated with a port 26) that requires to be operated by an operator.

[0030] There are three ports 26 shown in Fig. 1 and 2 denoted consecutively 26a, 26b, 26c from the heel 14 towards the toe 16 of the well and a respective downhole device 44a, 44b, 44c is associated with each port 26a, 26b, 26c. The control devices 44 are shown incorporated in part of a sand screen 24 although it should be noted that the sand screen 24 is not essential and may or may not be included in the tubing 42 around the respective port 26, particularly if the wellbore is not prone to sand ingress.

[0031] As shown in Figs. 1 and 2, each control device 44 is connected to and is capable of controlling a respective downhole tool 100 comprising a controllable and moveable sleeve 100 which covers a respective port 26 and again each sleeve is consecutively denoted 100a, 100b, 100c from the heel 14 to the toe 16 of the well. In general, the sleeves 100a, 100b, 100c are selectively controllable (by the respective control device 44 as will be detailed subsequently) to move between the first configuration shown in Fig.1 in which they are covering and thereby obturating the ports 26a, 26b and 26c respectively (thus preventing fluid flow through the ports 26a, 26b and 26c between the throughbore 40 of the production tubing 42 and the annulus 43 of the wellbore), and the second configuration shown in Fig.1 in which the sleeves 100a, 100b, 100c have been moved away from and have therefore uncovered the ports 26a, 26b and 26c

respectively (thus permitting fluid communication and therefore fluid flow through the ports 26a, 26b and 26c between the throughbore 40 of the production tubing 42 and the annulus 43 of the wellbore).

[0032] It should however be noted that other forms of downhole tool 100 (other than downhole sleeves) could be controlled by embodiments of control device 44 in accordance with the present invention. Additionally, any number (i.e. a plurality) of downhole tools 100 (which may be downhole sleeves or other forms of downhole tool 100) could be controlled by the one control device 44 in accordance with the present invention.

[0033] At the toe 16 of the well, the production tubing 42 has a closed end and orifices 26d are provided adjacent the closed end. A sleeve 100d is provided to selectively obturate the orifices 26d at the toe 16 of the well. In Fig. 1, the sleeve 100d is shown as it will be positioned when the production tubing 42 is run in, with the orifices 26d in fluid communication with the annulus surrounding the production tubing 42. However, it could be that all the orifices 26 are run into the wellbore in the closed position.

[0034] An embodiment of a downhole control device 44 in accordance with the present invention is shown in Fig. 3.

[0035] As shown in Fig. 3, at the heart of the downhole control device 44 is a Micro Controller Unit (MCU) 202 which may be in the form of an integrated chip mounted on an integrated circuit board. The MCU 202 is powered by a suitable power source which is optionally a battery 66 which outputs a DC voltage which may be in the region of 22 volts (but other voltages could be output) and which is supplied to the MCU 202 via suitable power conditioning unit 204. The power conditioning unit 204 typically supplies the specifically required voltage to the MCU 202 (typically 3.3 volts) and optionally can also supply the specifically required voltage (typically 5 volts) for other components that require power in the downhole device 44.

[0036] The MCU 202 optionally comprises a small form computer having a memory or data storage facility (not separately shown), a microprocessor for processing data (not separately shown), a clock that provides the ability for the MCU 202 to perform at least one or more timing operation(s) (not separately shown) and data input/output connections (205, 59, 211, 212).

[0037] As is further shown in schematic form in Fig. 3, each downhole device 44 comprises an RFID reader 60 which in turn comprises an antenna 62. A preferred antenna 62 is disclosed in WO2009/050518 to Petrowell Limited of Aberdeen, UK. The antenna 62 itself is optionally cylindrical and has a bore extending longitudinally therethrough and is arranged to be accommodated co-axially within the tubing 42. The inner surface of the antenna 62 may be flush with an inner surface of the adjacent production tubing 42 so that there is no restriction in the throughbore 40 in the region of the antenna 62. The antenna 62 optionally comprises an inner liner and a coiled conductor in the form of a length of copper wire that is concentrically wound around the inner liner in a helical coaxial manner. Insulating material optionally separates the coiled conductor from the recessed portion (not shown) of the sub in which the

antenna is co-axially arranged within, in the radial direction. The liner and insulating material are formed from a non-magnetic and non-conductive material such as resin, fibreglass, rubber or the like. The antenna 62 is formed such that the insulating material and coiled conductor are sealed from the outer environment and the throughbore 40. The antenna 62 may be in the region of 1 metre or less in length and more preferably is in the region of 40 cm in length. Accordingly, RFID reader 60 comprising an RFID antenna 62 is optionally provided within the downhole device 44 in a manner similar to the RFID reader disclosed in WO2009/050518 to Petrowell Limited of Aberdeen, UK but the RFID reader 60 and associated RFID antenna 62 could be provided as part of a separate downhole tool or sub-tool. In any case, the RFID reader 60 and associated RFID antenna 62 is connected to a power and data input/output 59 of the MCU 202 via suitable wiring such that the MCU 202 can both power the RFID reader 60 and/or supply data to the RFID reader 60 that as will be described can be used to charge up and then transmit data to a passing RFID tag or can read data from a passing RFID tag and transmit that data to the MCU 202 via the data input 59.

[0038] A pressure transducer sensor 210 is connected to a data input 211 of the MCU 202 via suitable wiring with suitable signal conditioning 213 therebetween and, as will be described in more detail subsequently, the pressure transducer is arranged in the downhole device 44 such that it can sense the pressure of downhole fluid surrounding the downhole device 44 and supply the associated data about the pressure reading it takes to the MCU 202 either on an automatic basis or more preferably on a controlled basis when requested by the MCU 202 to do so.

[0039] A controllable electrical power output 205 of the MCU 202 is connected to a motor drive 206 via suitable wiring and which when operated will mechanically drive a pump 208 to pump hydraulic fluid to do the desired work (such as open a sleeve 100) assuming that a spool valve 215 is aligned in the appropriate configuration as will now be described.

[0040] A further controllable electrical power output 212 of the MCU 202 is connected to a second motor drive 214 via suitable wiring and which (when operated by the MCU 202) will mechanically drive a spool valve 215 which can be arranged to move or translate between at least two positions or configurations. The spool valve has a first position or configuration in which the hydraulic output of the pump 208 is not in fluid communication with the sleeve 100 and therefore the hydraulic fluid is prevented from moving downhole sleeve 100. Furthermore, the spool valve 215 has a second position or configuration in which the hydraulic output of the pump 208 is in fluid communication with the sleeve 100 and therefore the hydraulic fluid output by the pump 208 (if the latter is actuated by the MCU 202) is permitted to flow to the downhole tool 100 such that it does the desired work (such as open the sleeve 100). The MCU 202 may additionally provide a further timing operation (not shown) so that once either the RFID antenna 62 or the pressure transducer 210 have read a signal that corresponds to an actuation command for actuating e.g. the sleeve 100 (by means of the pump 208 and spool valve 215), the actual step of actuation can be carried out at a predetermined time interval after the signal/command is received.

[0041] A suitable sliding sleeve 100 and a suitable sub containing ports 26 are disclosed in WO2009/050518 to Petrowell Limited of Aberdeen, UK.

[0042] RFID tags (not shown) for use in conjunction with the antenna 62 described above can be those produced by Texas Instruments such as a 32mm glass transponder with the model number RI-TRP-WRZB-20 suitably modified for use downhole. The tags should be hermetically sealed and capable of withstanding high temperatures and pressures. Glass or ceramic tags are preferable and should be able to withstand pressure of 20 000 psi (138 MPa). Oil filled tags are also well suited to use downhole, as they have a good collapse rating. The skilled person will realise however that other suitable RFID tags can be used.

[0043] Prior to being run into the well, the tubing 42 is made up incorporating a plurality of downhole devices 44. The devices 44 may be located spaced apart along the tubing string 42 so that once run in, they will be positioned adjacent areas of the formation 10 that contain hydrocarbon reservoirs of interest. Once a borehole has been drilled and the well is ready to be completed, the tubing 42 is run downhole into the position shown in Fig. 2. As the tubing 42 is run downhole, the sleeves 100a, 100b, 100c of each of the downhole devices 44 are in the closed position, in which the sleeve 100 substantially obturates the respective ports 26, except for orifices 26d positioned at the end of the tubing 42. At the end of the tubing 42, the sleeve 100d is in the second open configuration in which the orifices 26d are in fluid communication with the annulus surrounding the tubing 42. However, the skilled person will realise that other suitable running in configurations can be used.

[0044] In one embodiment of a method of controlling the wellbore in accordance with the present invention, kill fluid is then pumped downhole into the well. The kill fluid is optionally a high density mud that substantially restricts egress of reservoir fluids out of the formation 10 and into the tubing 42 or the annulus surrounding the tubing 42. The sleeves 100a, 100b, 100c remain in the first closed position in Fig. 2 with the ports substantially obturated while the kill fluid is pumped downhole. Since the sleeves 100a, 100b, 100c obturate the respective ports 26a, 26b, 26c, there is no access to the annulus from the throughbore 40 until the end open orifices 26d are reached at the toe 14 of the well. As a result, an operator can be sure that kill fluid pumped into the throughbore 40 of the tubing 42 reaches the toe 14 of the well once the requisite volume of kill fluid has been pumped downhole. Therefore, complete circulation of kill fluid can be achieved by pumping fluid directly down the tubing 42 since the kill fluid cannot escape through the ports 26a, 26b, 26c. However, the skilled person will realise that other suitable methods of controlling the well can be employed by the operator.

[0045] Embodiments in accordance with the present invention of the process steps that the MCUs 202 of one, some or all of the downhole devices 44 shown in Figs. 1 and 2 follow will now be described.

[0046] The power on stage of the MCU 202 is shown as START 300 in Fig. 4. The MCU 202 may be powered on at stage START 300 at the surface of the well prior to the downhole device 44 being run into the well 12 or it could be powered on by a separate timer system switching

the MCU 202 on after a particular time has lapsed or indeed could be switched on by a suitable switching device for a downhole tool such as that disclosed in WO2009/109788 to Petrowell Limited of Aberdeen, UK. Once the MCU 202 has been powered on at stage START 300, a first timing operation referred to as TIMER 1 is initiated at stage 302 and that loads a start value (for example 16 milliseconds) from a predetermined register stored in suitable non-volatile memory (not shown separately) associated with the MCU 202. That start value of for example 16 ms which is delivered to TIMER 1 at stage 302 could however be changed for instance by data that is transmitted from the switching device that is disclosed in WO2009/109788 to Petrowell Limited of Aberdeen, UK.

[0047] Thereafter, a second timing operation referred to as TIMER 2 is initiated at stage 304 and a start value, for example 10 seconds, is loaded into TIMER 2 from non-volatile memory.

[0048] A third timing operation referred to as TIMER 3 is thereafter initiated at stage 306 and is provided with a load start value which could be for a longer period such as many days, weeks or even months.

[0049] Optionally, each TIMER 1, 2 and 3 is associated with a separate task and, as will be described subsequently in more detail, in this example those tasks are as follows:-

TIMER 1 = operation of an RFID reader 60;

TIMER 2 = operation of a pressure transducer 210; and

TIMER 3 = operation of a contingency action, such as instructing all associated downhole tools 100 to open.

[0050] The separate results of initiating TIMER 1 (at stage 302), TIMER 2 (at stage 304) and TIMER 3 (at stage 306) will be detailed subsequently.

[0051] The MCU 202 then enters an endless loop at return point or stage 312.

[0052] The first stage of the endless loop comprises a step "LOOK FOR USER INTERVENTION" noted as 308 in Fig. 4. This stage 308 is particularly useful if the downhole device 44 starts (at START stage 300 in Fig. 4) with none of INTERRUPT SERVICE ROUTINES (ISR) 1, 2 or 3 enabled, as will be discussed in detail subsequently. If this is the case, then the MCU 202 will look at the "LOOK FOR USER INTERVENTION" stage 308 for separate specific instructions from the user or operator of the downhole device 44 and such separate specific instructions can be transmitted by means of a separate data transmission device such as the switching device for a downhole tool disclosed in WO2009/109788 to Petrowell Limited.

[0053] However, if no instructions are received at stage 308 to the contrary, then the

microprocessor 202 will move to stage 310 of "DO WORK" which entails the MCU 202 looking at its associated memory buffer for valid flags. If valid flags are present in the associated memory buffer then the MCU 202 will suspend looking for the interrupt created by the ISR 1, ISR 2 or ISR 3 (as will be detailed subsequently) and will do whatever the valid flag instructions instruct (i.e. open downhole sleeve 100B for example).

[0054] Once the MCU 202 has completed the "DO WORK" stage 310, the MCU 202 returns to return/entry point 312 and then starts the endless loop again by proceeding to step "LOOK FOR USER INTERVENTION" 308.

[0055] As discussed above, the MCU 202 is provided with an INTERRUPT SERVICE ROUTINE (ISR) for each of the timing operations TIMER 1 (302), TIMER 2 (304) or TIMER 3 (306). In general, the interrupt service routines ISR 1 (350), ISR 2 (400) and ISR 3 (450) can each store flags in the memory buffer associated with the MCU 202 and in doing so can instruct the MCU 202 to do different work at stage DO WORK 310 depending upon the instructions sent from the surface by the operator of the downhole device 44 (and in the case of ISR 3 will instruct the MCU 202 to do the pre-determined contingency action without needing a specific signal to be sent from the surface by the operator of the downhole device 44).

[0056] Fig. 5 shows INTERRUPT SERVICE ROUTINE (ISR) 1 (350) and which is associated with stage INITIATE TIMER 1 (302) of Fig. 4.

[0057] In this embodiment, stage INITIATE TIMER 1 (302) loads a start value of 16 milliseconds into TIMER 1 and TIMER 1 counts down to zero seconds and when TIMER 1 reaches zero seconds, it then resets back to its start value of 16 milliseconds and counts down again to zero seconds and this countdown is repeated until the downhole device 44 is switched off or the battery 66 runs out of power.

[0058] ISR 1 (350) is arranged to observe when TIMER 1 (302) underflows and such an underflow condition is when TIMER 1 (302) reaches zero and then resets back to 16 milliseconds.

[0059] At the point that TIMER 1 (302) underflows, the ISR 1 (350) starts and progresses to stage 352 "TURN OFF CHARGE". Stage 352 turns off the charge that is applied to the RFID antenna 62 (the antenna 62 having previously been charged).

[0060] The next stage is "LISTEN FOR TAG" 354 in which the RFID reader 60 monitors the output of the RFID antenna 62 and observes whether or not an RFID tag (not shown) is present within the RFID antenna 62, the RFID tag (not shown) having been dropped into the fluid being pumped down the throughbore 40 of the production tubing 42 at the surface of the well by the operator.

[0061] Stages 352 and 354 combined together take approximately 2 milliseconds and therefore mean that the RFID antenna 62 is not supplied with power from the battery 66 for

those two milliseconds and therefore have the great advantage that that battery power 66 is saved for those two milliseconds. Considering that the RFID antenna 62 will be switched on after stage 354 has completed (i.e. after two milliseconds has passed) that means that there is an approximate 12.5% saving in the amount of power used by the RFID antenna 62 (considering that the RFID antenna 62 will be switched on for the remaining 14 milliseconds of the 16 millisecond cycle associated with TIMER 1 (302)).

[0062] After stage 354 has been completed, Interrupt Service routine ISR 1 then moves to the next stage, "DECODE TAG" stage 356. If an RFID tag (not shown) was present within the RFID antenna 62 and was detected by the RFID reader 60, the MCU 202 will store a valid flag in its associated memory buffer along with the data transmitted by the RFID tag and received by the RFID reader 60 at the "DECODE TAG" stage 356.

[0063] The interrupt service routine ISR 1 (350) then moves to the "RETURN TO MAIN PROCESS" stage 358 (and hence in essence the MCU can be considered as having completed that routine ISR 1 until TIMER 1 underflows again at which point ISR 1 (305) (assuming it is enabled) will be commended again).

[0064] Accordingly, if a valid flag was placed into the memory buffer at stage 356 during Interrupt service routine ISR 1 (350), the MCU 202 will note that during the "DO WORK" stage 310.

[0065] Otherwise, ISR 1 (350) will run again and interrupt service routine ISR 1 (350) is repeated on the next underflow of TIMER 1 (and that will repeat each time TIMER 1 underflows).

[0066] Importantly, ISR 1 (350) can be switched/enabled on or off by an enable or disable routine 351 and the enable or disable routine 351 is also controlled by the MCU 202 and can be switched between enable or disable by instructions received from the surface by the operator transmitting data containing those instructions. The significant advantages that this feature provides will be discussed subsequently. Interrupt service routine ISR 2 (400) is shown in Fig. 6 and is associated with and operated by TIMER 2 (304). Upon power up of the downhole device at stage 300 in Fig. 4, TIMER 2 (304) is initially loaded with a start value of for example 10 seconds and TIMER 2 counts down from 10 seconds to zero and upon underflow wraps back round to its loaded start value of 10 seconds and that countdown, underflow and reset process repeats continuously.

[0067] ISR 2 (400) monitors for when TIMER 2 underflows and at that point ISR 2 (400) moves to its next stage of "TAKE PRESSURE READING" 402 and which takes a pressure reading from the pressure transducer 210 where the pressure transducer 210 provides a reading of the downhole fluid pressure at its location. That pressure reading is provided to stage 404 "RUN MATH CALCULATION" at which point the MCU 202 compares the pressure reading taken at stage 402 with at least the immediately previous pressure reading and calculates the change in pressure (that is it calculates the difference in the two pressure values) and also

calculates if that change is positive or negative and that information is stored in the MCU's 202 memory buffer.

[0068] ISR 2 (400) then moves to the next stage of "RETURN TO MAIN PROCESS" 406. The MCU 202 will therefore monitor and look for any valid flag that has been presented into its memory buffer by the ISR 2 (400) and if so will do the work that is associated with that valid flag and with the earlier stored pressure reading information, by comparing it against stored instructions so that the MCU 202 can then determine if an instruction has been sent and if so what that instruction means, during its "DO WORK" stage 310.

[0069] Consequently, operation of the MCU 202 will result in a pressure reading being taken and stored every 10 seconds and that will enable an operator at the surface to pressure pulse the downhole fluid and in a matter of minutes will enable the operator to transmit instructions to the MCU 202 because the MCU 202 has been previously provided with a set of instructions to store within its non-volatile memory to for example open sliding sleeve 100C if there is a particular series of pressure changes (for example, a relatively high pressure followed by a relatively low pressure repeated 3 times) within a particular time scale (for example 12 minutes).

[0070] Again, and importantly, the ISR 2 (400) can be enabled or disabled by switch 401 such that the ISR 2 (400) could for instance be disabled by an instruction sent from the surface by the operator by means of pressure pulsing (in that it can be instructed to switch itself off) or indeed such a signal could be transmitted from the surface by the operator by another transmission means or mechanism, e.g. by RFID tag that can be detected by ISR 1 (350) (assuming ISR 1 is enabled at that point in time by its switch 351).

[0071] ISR 3 (450) is shown in Fig. 7 and is associated with and operated by TIMER 3 (306). TIMER 3 (306) is initialised when the downhole device 44 is powered on START 300 and is loaded with a start value which could be a much longer period of time such as days, weeks or even months and ISR 3 (450) will again monitor the underflow of TIMER 3 and once it detects that underflow it will move to stage 452 "DO CONTINGENCY ACTION" which could be for example to open all downhole sleeves 100. Once stage 452 has been completed, ISR 3 will move to stage 454 "RETURN TO MAIN PROCESS". Importantly, ISR 3 (450) can again be enabled or disabled via switch 451 and therefore if the operator does not wish to allow ISR 3 (450) to operate, the operator can send a signal from the surface to the downhole device 44 to disable ISR 3 (450) via switch 451.

[0072] In practice, (assuming for example that the ISR 1 (350) is enabled via its switch 351 and that ISR 2 (400) is enabled via its switch 401) the MCU 202 will give the appearance of looking for both pressure pulsing (via ISR 2 (400)) and also RFID tags (via ISR 1 (350)) concurrently but in actual fact is multi-plexing between the two different transmission mechanism because it is running ISR 1 (350) and ISR 2 (400) in parallel but looks for the valid flags in its memory register in series.

[0073] Importantly, in practice, the ISR 1 (350) is likely to be switched off via its enable or disable switch 351 for a significant amount of time that the downhole device 44 is in use because operating and powering the RFID antenna 62 uses approximately 10 times the amount of power that is used by the pressure pulse detection method operated by ISR 2 (400). Accordingly, it is likely in practice that the operator will use ISR 2 (400) to send instructions via pressure pulsing to the MCU 202 to switch on ISR 1 (350) by switching on its enable or disable switch 351 (RFID tags being able to contain a lot more data and also can transmit that data at a much higher data burst rate than can be sent via the relatively slow data rate of the pressure pulse method).

[0074] Accordingly, in practice, the completion that is shown in Fig. 1 could be run in with all the downhole tools 100 closed and with ISR 1 (350) switched off via its switch 351. The operator could then send pressure pulses with a particular code that is detected by the pressure transducer 210 and decoded by the MCU 202 and that code could for instance instruct the MCU 202 during its DO WORK stage 310 to switch on enable switch 351 immediately (or could instruct ISR 1 (350) to switch on in a number X of hours time) and could also instruct ISR 1 (350) to remain switched on for a number Y of hours thereafter and therefore look for RFID tags in that period of time when it is switched on.

[0075] Consequently, the ability to switch between the two data transmission mechanism of RFID Tags and pressure pulsing enables the operator to be able to choose the highest data transfer rate but also allows the operator to conserve the valuable battery power.

[0076] The operator will likely keep the relatively low power pressure pulse transmission method switched on all the time via its enable switch 401 in order to provide at least one data transmission method at all times. For instance, if the operator is sending pressure pulses to a lower most downhole device 44C with a 3 minute pressure pulse and it does not open its associated downhole tool 100C for any reason, the operator can take the decision to abandon that downhole tool 100C and instead instruct the next highest downhole device 44B to open its associated downhole tool 100B with, for example a 5 minute pressure pulse. Accordingly, by keeping ISR 2 (400) switched on all the time via its enable switch 401, the operator will always have the contingency of being able to send pressure pulses (assuming pressuring up the downhole fluid is possible).

[0077] An RFID tag (not shown) is programmed at the surface by an operator to generate a unique signal according to the present embodiment. Similarly, prior to being included in the device 44 at the surface, each of the electronics packs coupled to the respective antenna 62, is separately programmed to respond to a specific signal. The RFID tag comprises a miniature electronic circuit having a transceiver chip arranged to receive and store information and a small antenna within the hermetically sealed casing surrounding the tag.

[0078] One or more pre-programmed RFID tag(s) is/are then weighted if required, and dropped or flushed into the well with the kill fluid. Alternatively, the tag can be circulated through the tubing 42 to reach the devices 44 with brine or diesel flushed downhole after the

kill fluid.

[0079] After travelling through the vertical portion 12 and throughbore 40 of the tubing 42, the selectively coded RFID tag reaches the downhole devices 44 that the operator wishes to actuate. The tag passes through the throughbore 40 and the antenna 62 of each device 44. During passage of the RFID tag (not shown) through the throughbore 40, the antenna 62 of the device 44 in question is of sufficient length to charge and read data from the tag. The tag then transmits certain radio frequency signals, enabling it to communicate with the antenna 62. This data is processed by the MCU 202 in the manner described in detail subsequently.

[0080] According to the present example, the RFID tag has been programmed at the surface by the operator to transmit information instructing that a particular sliding sleeve 100a, 100b, 100c is to be opened.

[0081] Several tags programmed with the same operating instructions for individual devices 44 can be added to the well, so that at least one of the tags will reach the desired antenna 62 enabling the operating instructions to be transmitted. Once the data is transferred to the device 44, the other RFID tags encoded with similar data can be ignored by the antenna 62.

[0082] In practice there are likely to be many more devices 44 spaced axially along the tubing 42 than shown in the schematic on Figs. 1 or 2. Several devices 44 adjacent a particular part of the formation 10 can be opened simultaneously. Certain devices 44 can remain in the closed configuration if data is gathered to suggest to an operator that an adjacent formation 10 contains mainly gas or water. Alternatively, where the downhole devices 44 are mounted on coiled tubing and run in as part of a frac'ing operation, one or more selected downhole control devices 44 can be actuated depending up on the required frac'ing operation.

[0083] According to an alternative embodiment, and particularly if a complicated downhole tool 100 sequence of operations is required, all the ISR 2's (400) of each downhole device 44 can be switched on via their respective enable switches by sending the appropriate pressure pulse sequence and thereafter, in order to actuate a specific downhole tool 100, a tag programmed with a specific signal is sent downhole. Each antenna 62 is either responsive to the signal of a specific tag or is responsive to all tags and the decoding is done by the MCU 202 to determine if it is the downhole tool 100 associated with that MCU 202 that is to be actuated. In this way tags can be used to selectively target certain devices 44 by pre-programming the antennas 62 or the MCU's 202 and corresponding tags. Thus, several different tags may be provided to target different devices 44.

[0084] The tags may also be designed to carry data transmitted from antennas 62, enabling them to be re-coded during passage through the tubing 42. In particular, useful data such as temperature, pressure, flow rate and any other operating conditions of the device can be transferred to the tag. The antenna 62 can emit a radio frequency signal in response to the radio frequency signal it receives. This can re-code the tag with information sent from the antenna 62.

[0085] Additionally, and as described above, signals can be sent from the surface to the MCU 202 to operate the downhole devices 100 by sending pressure pulses through the wellbore fluid (either in the throughbore 40 of the tubing 42 or through the fluid located in the annulus 43, wherein such pressure pulses are sensed by the pressure transducer 210 of each device 44. Additionally, or alternatively, the MCU 202 may be pre-programmed to be responsive to any pressure above a threshold (in the most simple form) or to be responsive to pressure pulses in the form of a pre-determined pressure signature, in which case the MCU 202 is pre-programmed to identify rates of change with a certain repetition rate of the pressure pulses to avoid spurious actuation.

[0086] The method of the invention does not have to be used in conjunction with every single specific downhole device 44 described herein. According to an alternative embodiment, the production tubing 42 or coiled tubing 42 may be provided with one or more modified devices 44 containing some other form of control mechanism such as a timer for operating a downhole tool 100.

[0087] According to the above embodiment, the sleeves 100a, 100b, 100c, 100d are described as moveable between a first closed and a second open configuration. However, the sleeves may also be movable to a plurality of intermediate configurations in which the sleeve 100 partially obturates the ports 26 to controllably and selectively restrict or choke but not completely stop the flow of fluid.

[0088] The embodiment described herein has the advantage that the MCU 202 is in practice always receptive to either pressure pulse signals or RFID signals rather than the prior art disadvantage of for example an RFID reader able to seek or read an RFID signal only where there is circulation of fluid or only able to sense pressure pulse signals only when the tubing is closed. Therefore in a situation where the tubing 42 becomes blocked and the capacity for flow of fluid therethrough is restricted, the MCU 202 can still respond to pressure pulse signals as a result of the ability of the MCU 202 to multiplex the respective signals.

[0089] Other methods of remote actuation of the devices can also be used in addition to RFID tags and associated RFID Readers 60 and/or pressure pulses and associated pressure transducers 210. For example, the devices 44 can be provided with suitable sensors to respond to acoustic or electromagnetic signals. For example, other but different remote control methods of communicating could be used in one or more modified downhole control devices instead of RFID tags and sending pressure pulses down the completion fluid located in the throughbore of the production tubing 42 such as an acoustic signalling system such as the EDGE^(TM) system offered by Baker Oil Tools of Houston, Texas, USA or an electromagnetic wave system such as the Cableless Telemetry System offered by Expro Group of Verwood, Dorset, UK.

[0090] Modifications and improvements can be made without departing from the scope of the invention. The ports can be obturated by means other than a sleeve. For example, if the

sleeve is part of a sandscreen sub, actuation of the mechanism for moving the obturation member between first and second configurations can cause movement of an annular plate rather than a sleeve to selectively obturate the ports. In addition, for example, a downhole power generator can provide the power source in place of the battery pack. A fuel-cell arrangement can also be used as a power source.

REFERENCES CITED IN THE DESCRIPTION

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PATENTKRAV:

1. Fremgangsmåde til styring af et borehulsværktøj (100) i en brønd med en borehulsbearbejdningsanordning (202), hvilken fremgangsmåde omfatter trinene:
 - 5 lagring af data modtaget fra en RFID-taglæser (60) under en første tidsstyringsoperation (302) i en datalagringsenhed, hvor RFID-taglæseren (60) er indrettet til at læse data fra og/eller sende data til et passerende RFID-tag;
 - 10 tjek af datalagringsenheden for eventuelt lagret data modtaget fra RFID-taglæseren (60) mindst én gang under eller efter den første tidsstyringsoperation (302),
 - 15 hvor RFID-taglæseren (60) yderligere omfatter en RFID-antenne (62), der er indrettet til at læse data fra RFID-tagget, der er bevægeligt i forhold til RFID-antennen (62);
 - og
 - lagring af data modtaget fra en borehulsvæsketrykpulssensor (210) under en anden tidsstyringsoperation (304) i datalagringsenheden, hvor
 - 20 borehulsvæsketrykpulssensoren (210) er i stand til mindst at modtage et signal sendt via ændringer i trykket i borehulsvæsken, der er i forbindelse med borehulsvæsketrykpulssensoren (210);
 - tjek af datalagringsenheden for eventuelt lagret data modtaget fra borehulsvæsketrykpulssensoren (210) mindst én gang under eller efter den anden
 - 25 tidsstyringsoperation (304);
 - hvor hver af den første (302) og anden (304) tidsstyringsoperation er baseret på den tid, der tilvejebringes af et ur i borehulsbearbejdningsanordningen (202); og
 - hvor den første (302) og anden (304) tidsstyringsoperation omfatter respektive første og anden timere;
 - 30 styring af borehulsværktøjet (100) baseret på instruktioner indeholdt i de lagrede data; inkludering af tilvejebringelse af respektive kontakter (351, 401), der er i stand til at aktivere eller deaktivere henholdsvis RFID-taglæseren (60) og borehulsvæsketrykpulssensoren (210);
 - programmering af RFID-tagget af operatøren på overfladen med data til tilvejebringelse af et signal eller instruktioner, der kan modtages af RFID-taglæseren (60), og bevægelse af RFID-tagget ned i brønden fra overfladen til i nærheden af RFID-taglæseren (60) til tilvejebringelse af dataene til datalagringsenheden, således at borehulsbearbejdningsanordningen (202) instrueres i at operere eller aktivere borehulsværktøjet;
 - 35 ændring af trykket af borehulsvæske i nærheden af borehulsvæsketrykpulssensoren (210) ved ændring af trykket af væske på overfladen af brønden til sending af et signal til borehulsvæsketrykpulssensoren (210) via ændringer i trykket af borehulsvæsken, der er i forbindelse med borehulsvæsketrykpulssensoren (210), hvor signalet modtages af

- borehulvæsketrykpulssensoren (210), som tilvejebringer dataene til datalagringsenheden, således at borehulsbearbejdningsanordningen (202) instrueres i at operere eller aktivere borehulsværktøjet; og
- 5 når de respektive kontakter (351, 401) er aktiveret for RFID-taglæseren (60) og borehulvæsketrykpulssensoren (210), udfører borehulsbearbejdningsanordningen (202) den respektive første (302) og anden (304) tidsstyringsoperation parallelt med hinanden, men søger efter gyldige dataflag(s) i datalagringsenheden i serier.
- 10 2. Fremgangsmåde til styring af et borehulsværktøj i en brønd ifølge krav 1, hvor den første (302) og anden (304) tidsstyringsoperation bestemmer, hvornår de lagrede data modtaget fra RFID-taglæseren (60) og borehulsvæsketrykpulssensoren (210) tjekkes; hvilken fremgangsmåde indbefatter lagring af den første og anden forudbestemte tidsværdi i en hukommelseslagringsenhed og tilvejebringelse af den første og anden forudbestemte tidsværdi til den respektive første (302) og anden (304)
- 15 tidsstyringsoperation ved initiering af borehulsbearbejdningsanordningen (202).
- 20 3. Fremgangsmåde til styring af et borehulsværktøj i en brønd ifølge et hvilket som helst af kravene 1-2, som indbefatter udløsning af borehulsbearbejdningsanordningen (202) til tjek af datalagringsenheden, når den første tidsstyringsoperation (302) underløber eller genindstiller fra nul til en forudbestemt tidsværdi, som tidsstyringsoperationen herefter vil tælle ned til nul fra; og indbefatter udløsning af borehulsbearbejdningsanordningen (202) til tjek af datalagringsenheden, når den anden tidsstyringsoperation (304) underløber eller genindstiller fra nul til en forudbestemt værdi, som tidsstyringsoperationen herefter vil tælle ned til nul fra.
- 25 4. Fremgangsmåde til styring af et borehulsværktøj i en brønd ifølge et hvilket som helst af kravene 1-3, som indbefatter tilvejebringelse af en relativ kort forudbestemt værdi for den første tidsstyringsoperation sammenlignet med en forudbestemt værdi for den anden tidsstyringsoperation.
- 30 5. Fremgangsmåde til styring af et borehulsværktøj i en brønd ifølge et hvilket som helst af kravene 1-4, hvor den første tidsstyringsoperation (302) omfatter en tidsstyret hændelse, der indbefatter en gentagende nedtælling fra den forudbestemte tidsværdi til nul, hvor den tidsstyrede hændelse gentages mindst én gang.
- 35 6. Fremgangsmåde til styring af et borehulsværktøj i en brønd ifølge et hvilket som helst af kravene 1-5, hvor den anden tidsstyringsoperation (304) omfatter en tidsstyret hændelse, der indbefatter en gentagende nedtælling fra den forudbestemte tidsværdi til

nul, hvor den tidsstyrede hændelse gentages mindst én gang.

- 5 7. Fremgangsmåde til styring af et borehulsværktøj i en brønd ifølge krav 6, når det er underordnet krav 5, hvor punktet, hvor den tidsstyrede hændelse genindstiller fra nul til den forudbestemte tidsværdi, omfatter en underløbsudløser, der udløser tjekket af de lagrede data modtaget fra den respektive RFID-taglæser (60) og borehulsvæsketrykpulssensor (210).
- 10 8. Fremgangsmåde til styring af et borehulsværktøj i en brønd ifølge et hvilket som helst af kravene 1-7, som indbefatter indretning af borehulsbearbejdningsanordningen (202) til lagring af data i datalagringsenheden, hvis den instrueres i at gøre dette, med forudbestemte tidsintervaller bestemt af den første (302) og anden (304) tidsstyringsoperation.
- 15 9. Fremgangsmåde til styring af et borehulsværktøj i en brønd ifølge et hvilket som helst af kravene 1-8, som indbefatter præprogrammering af borehulsbearbejdningsanordningen (202) til genkendelse af flags, der præsenteres af de lagrede data, og/eller tendenser i de lagrede data og indretning af borehulsbearbejdningsanordningen (202) til at reagere på flaggene eller tendenserne til styring af et borehulsværktøj (100).
- 20 10. Fremgangsmåde til styring af et borehulsværktøj i en brønd ifølge et hvilket som helst af kravene 1-9, hvor den første (302) og anden (304) tidsstyringsoperation omfatter selektivt aktiverbare respektive første (350) og anden (400) afbrydelsesservicerutiner.
- 25 11. Borehulsbearbejdningsapparat (44), som indbefatter en ikke-flygtig hukommelseslagring af den information, der er nødvendig til udførelse af fremgangsmåden ifølge kravene 1-10.

DRAWINGS

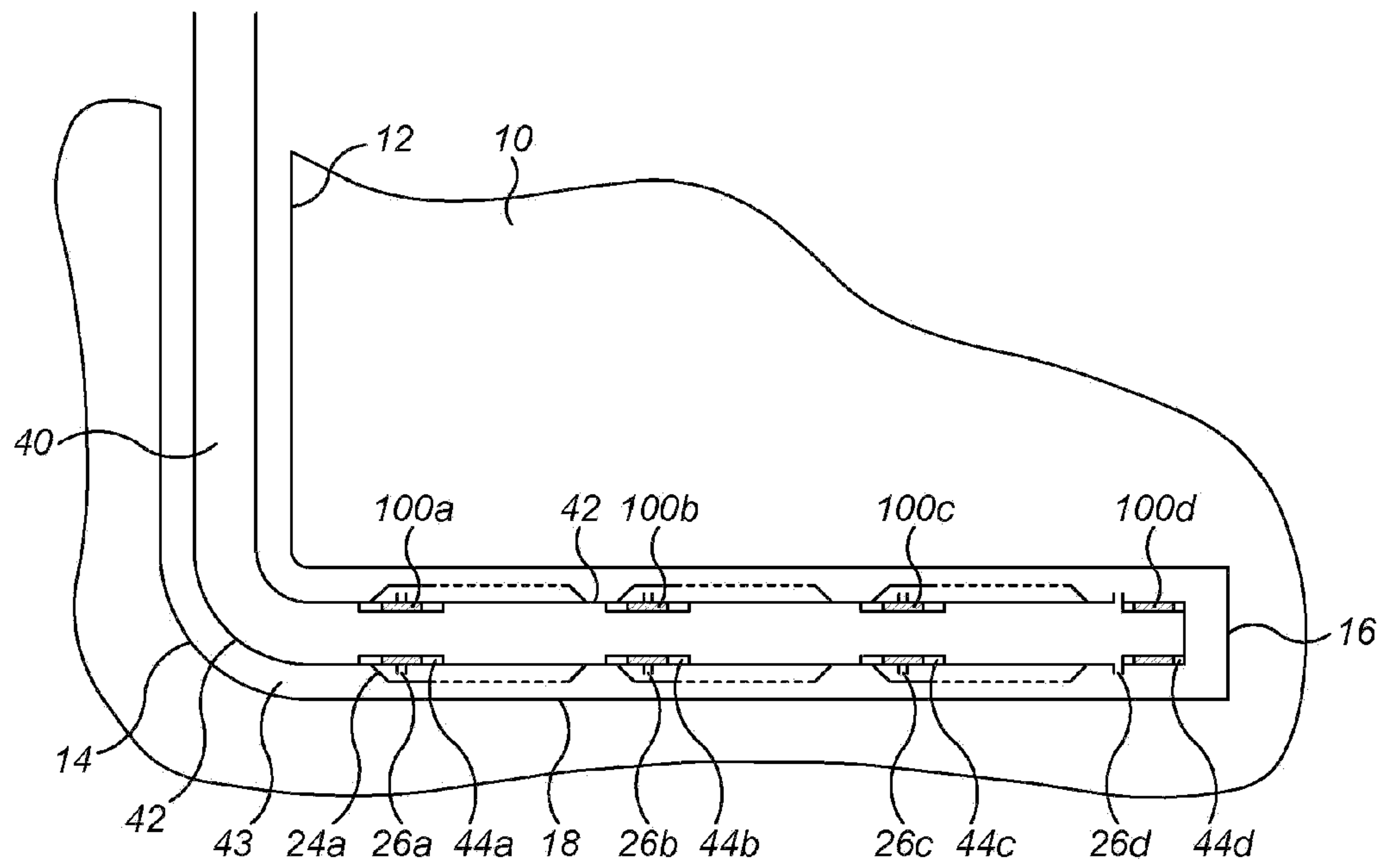


FIG. 1

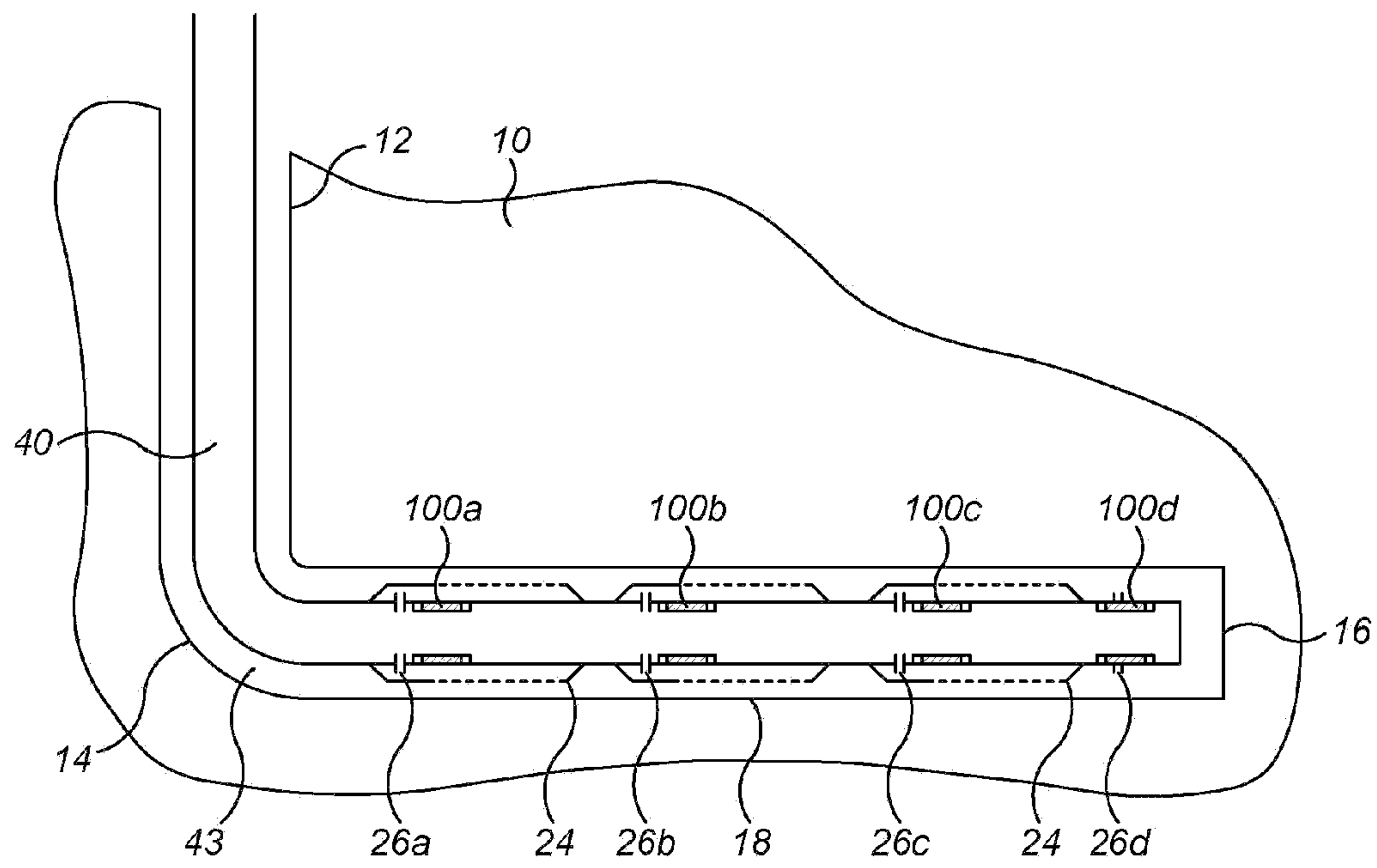


FIG. 2

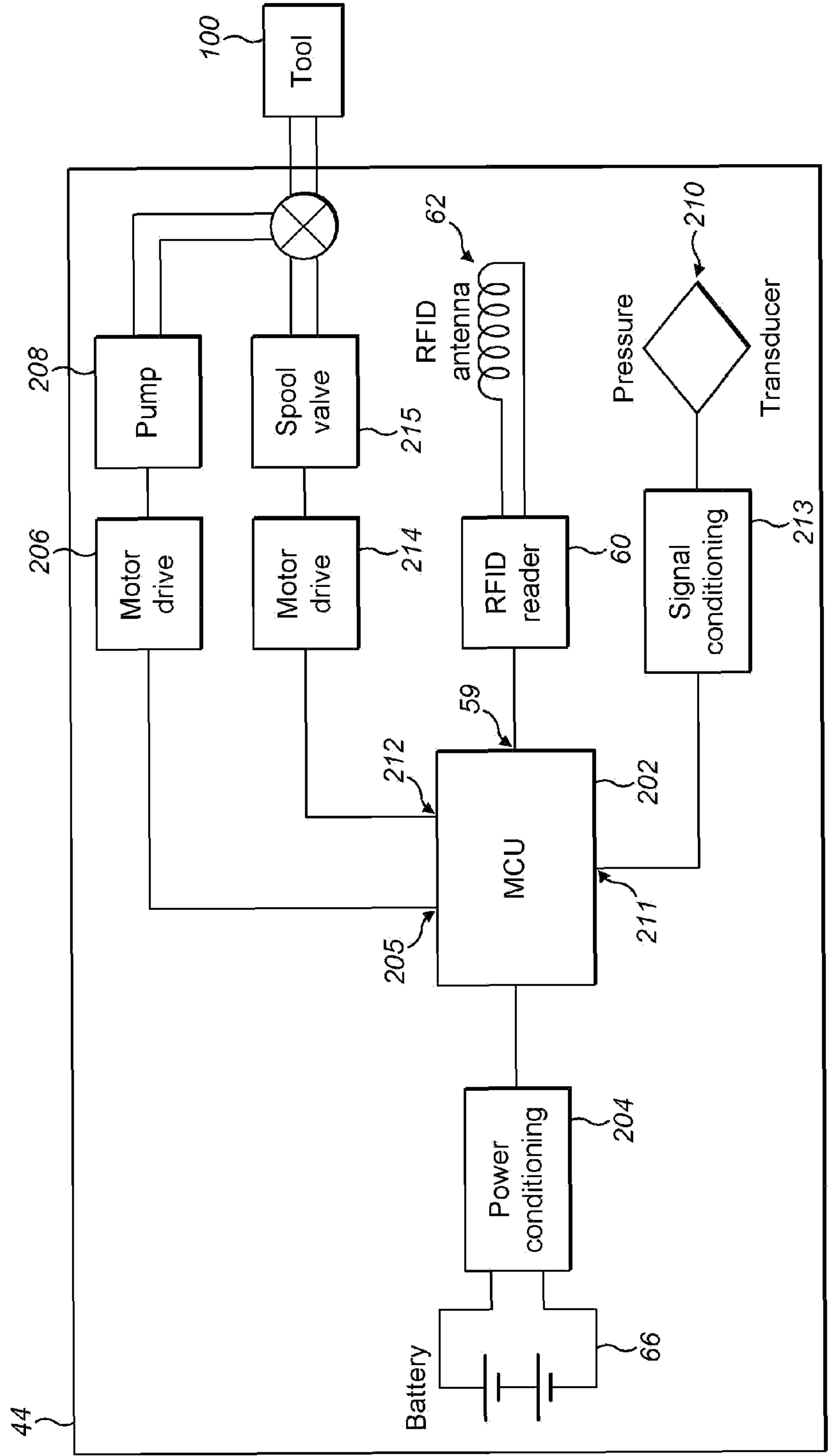
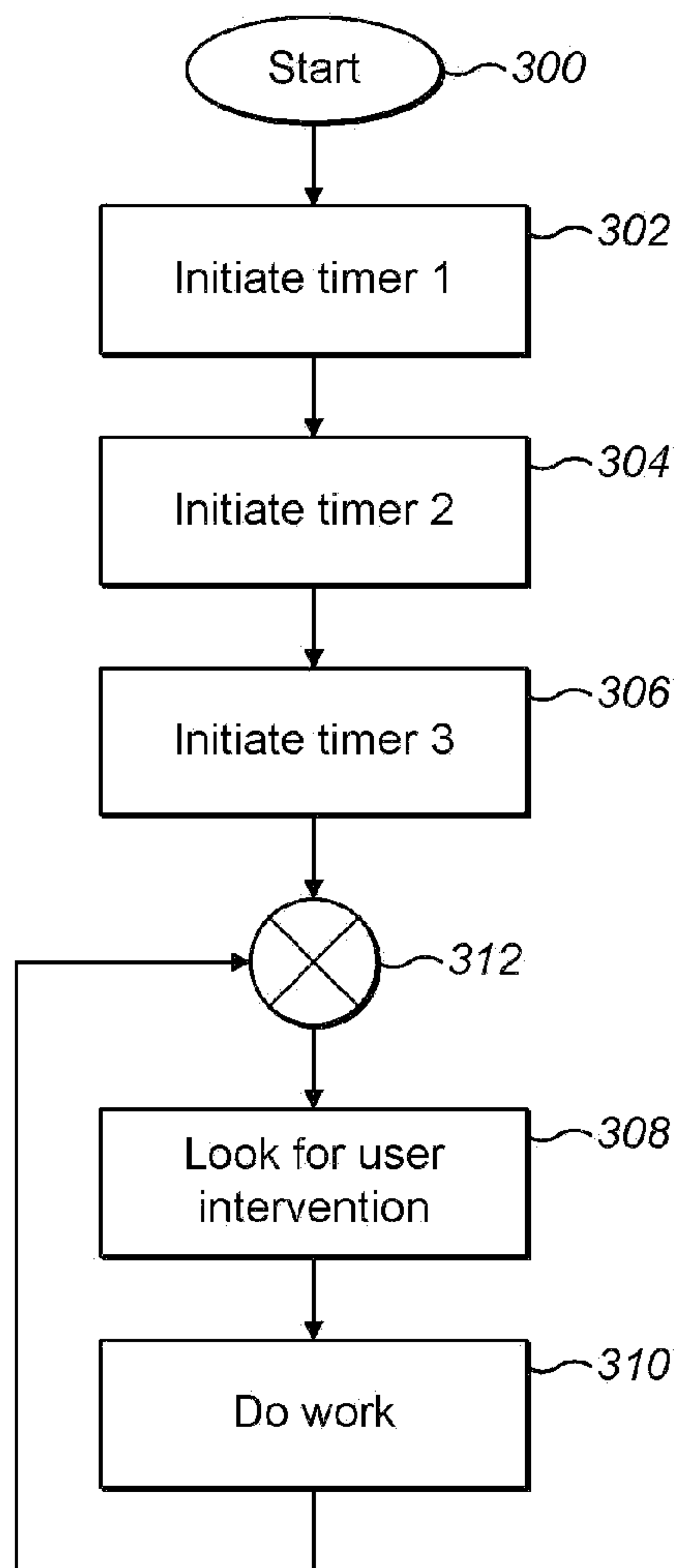
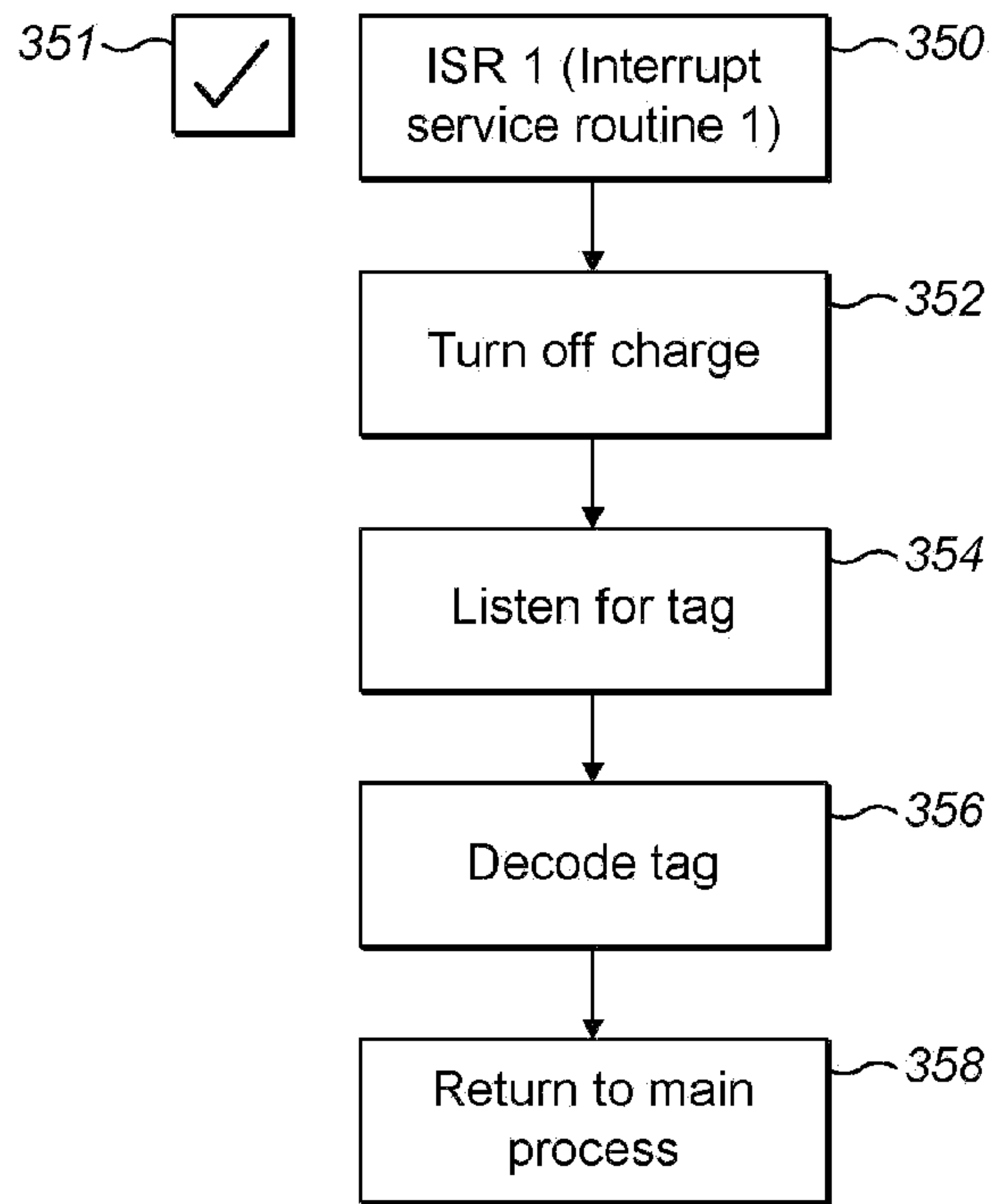
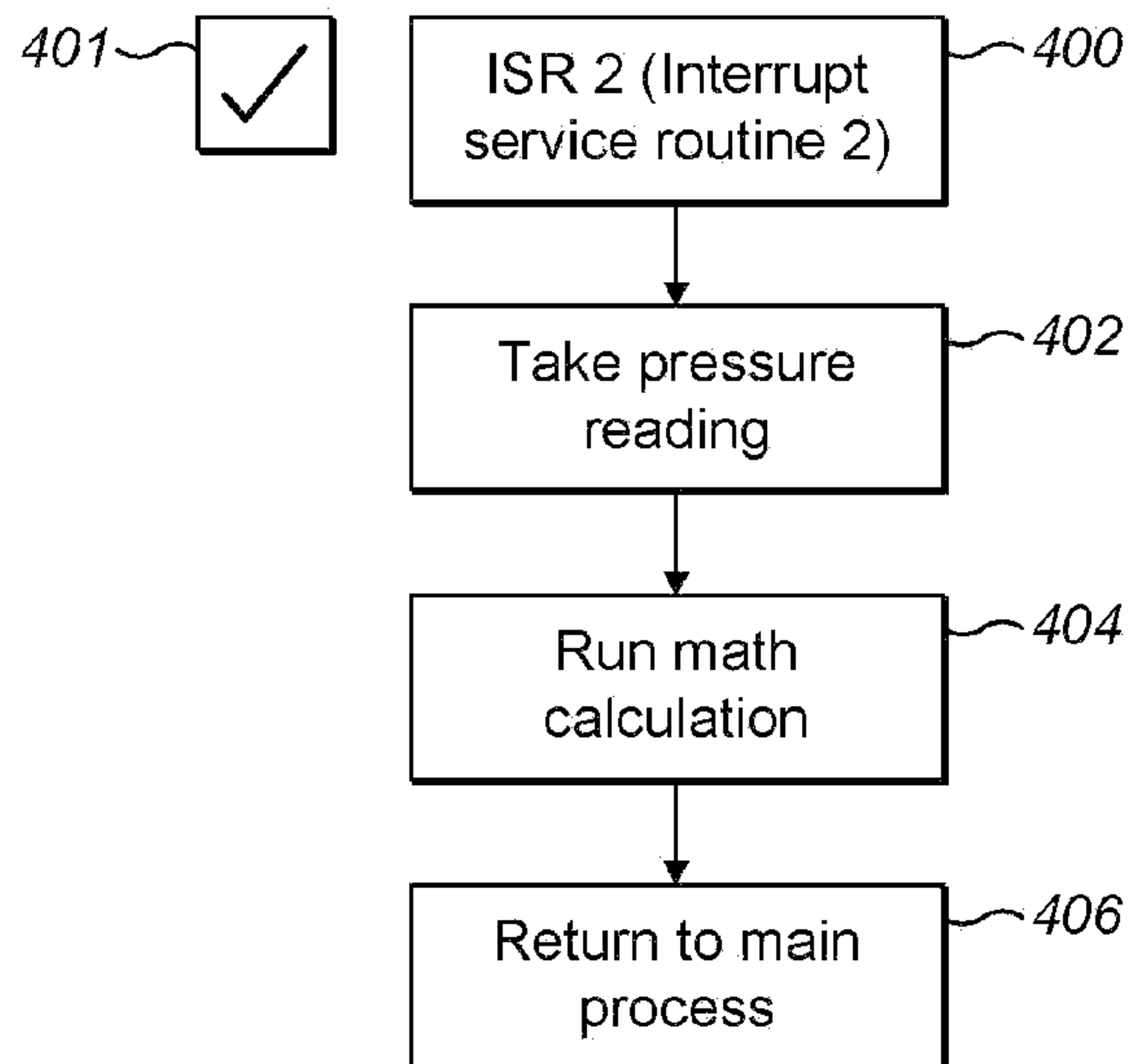
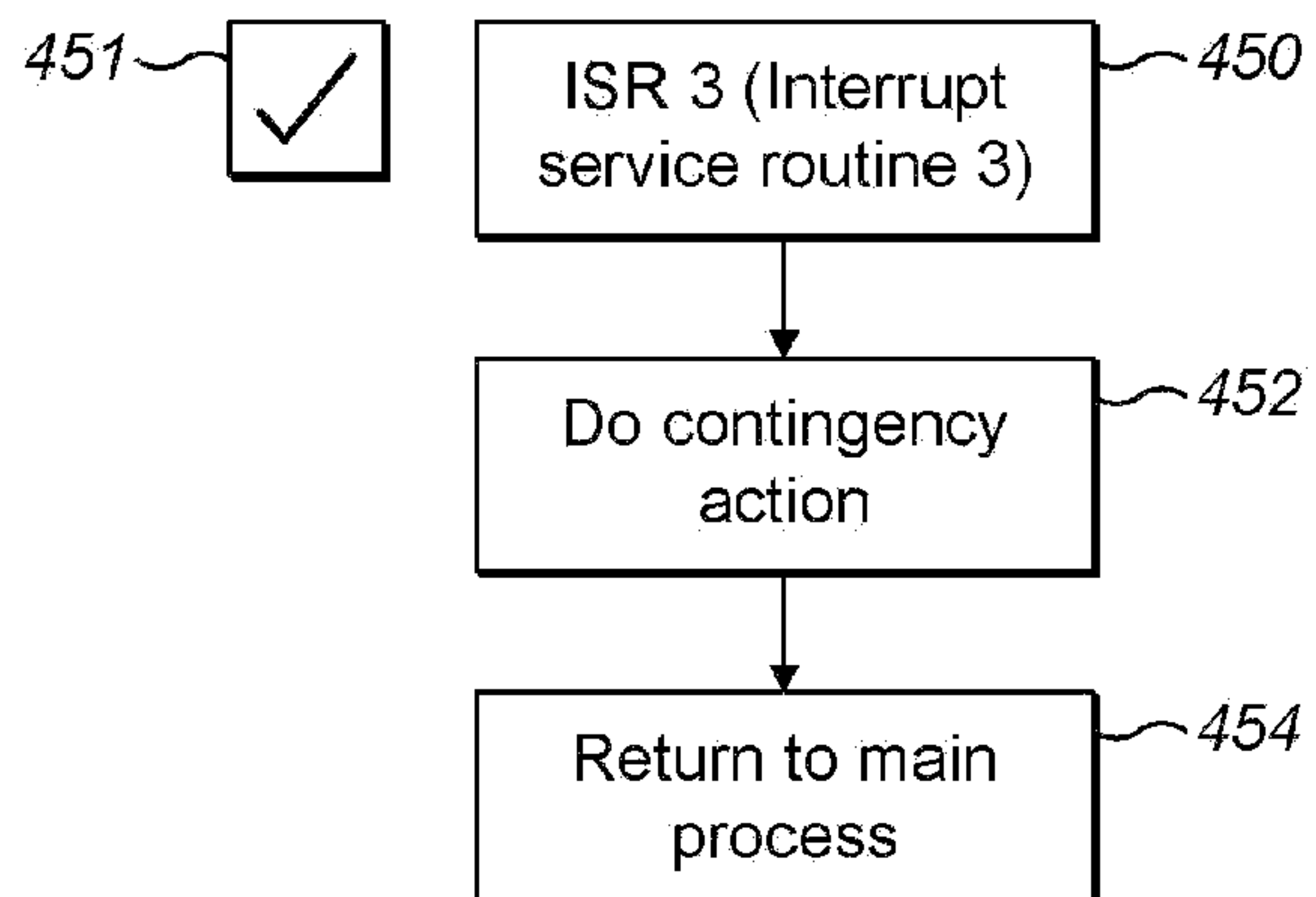


FIG. 3

**FIG. 4**

**FIG. 5**

**FIG. 6****FIG. 7**