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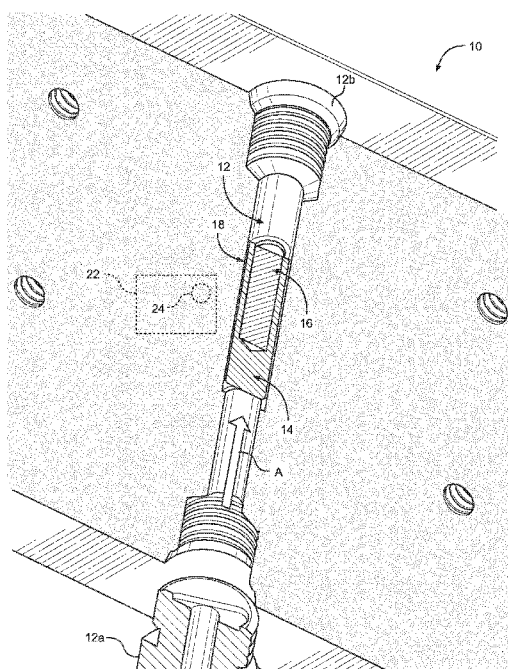


FIG. 1

(57) Abstract: A catalyst alarm system for resin/catalyst spray applications, the system having a first flow sensor that monitors whether a catalyst from a manifold is flowing for supply to a spray gun or other applicator at a specified minimum rate; a second flow sensor that detects if the catalyst is flowing out of a bypass conduit of the manifold, which indicates the catalyst is not being mixed with the resin; a third flow sensor that detects if the catalyst is flowing out of an over pressure conduit of the manifold, which indicates that only a partial amount of the required catalyst is being mixed with the resin; and monitoring circuitry for providing alarm and/or control features based on activation combinations of the three flow sensors.



CATALYST FLOW SENSOR

FIELD

[0001] This invention relates to catalyst delivery systems for short-fiber composite manufacturing processes. More particularly, this invention relates to catalyst flow sensors and associated methods and alarm systems that indicate and provide an alarm when catalyst is not flowing in a correct manner.

BACKGROUND

[0002] Liquid resins and catalysts used for spray applications associated with short-fiber composite manufacturing processes are typically mixed just before spraying and it is important to maintain the flows in desired amounts. The catalyst is an initiator for a polymerization reaction with the resin and the catalyst is typically highly reactive. Conventional flow sensors are unsuitable for use with highly reactive catalyst fluids and their typical process conditions involving high pressures.

[0003] Prior flow sensors have been found to be incompatible for use with catalysts due to the highly reactive nature of catalysts such as methyl ethyl ketone peroxide (MEKP), and high-pressure conditions, such as up to about 1500 psi, typically associated with such spray processes. Accordingly, what is desired is a flow sensing apparatus that is suitable for monitoring the flow of a liquid catalyst and for signaling when the flow is outside of a desired range.

[0004] The present disclosure advantageously provides catalyst flow sensors and associated delivery systems configured for use with liquid catalysts to detect when the flow rate of the catalyst is outside of a desired range. The sensors are configured for use with reactive catalysts under high pressure conditions, and the systems advantageously include an alarm or other indicators designed to alert a user when catalyst is not flowing as desired.

SUMMARY

[0005] The disclosure relates to liquid flow sensors, methods for monitoring liquid flows, and to flow monitoring systems.

[0006] In one aspect, the disclosure relates to a liquid flow sensor that includes an elongate flow tube having an inlet end and an outlet end. Liquid flows into the flow tube at the inlet end and exits from the outlet end. A float is located in the flow tube and configured for the liquid flowing in the flow tube to flow around the float, the float including a magnet. An electrical circuit is proximate the flow tube. The electrical circuit includes a magnetic sensor located proximate the float for sensing a position of the magnet in the flow tube. The position of the magnet in the flow tube is related to the position of the float in the flow tube, which is related to flow characteristics associated with flow of the liquid through the flow tube.

[0007] In another aspect, the disclosure provides a method of monitoring flow of a liquid. The method includes the steps of flowing a liquid under pressure through an elongate flow tube having an inlet end and an outlet end, wherein the liquid flows into the flow tube at the inlet end and exits at the outlet end; providing a float including a magnet in the flow tube, the float configured so that the liquid flowing in the flow tube flows around the float; directing the flow of liquid through the elongate flow tube to contact and flow around the float such that the position of the float in the flow tube is dependent upon the flow of liquid through the flow tube; and sensing a position of the magnet in the flow tube. The position of the magnet in the flow tube is related to the position of the float in the flow tube, which is related to flow characteristics associated with flow of the liquid through the flow tube.

[0008] In a further aspect, the disclosure relates to a flow monitoring system. The system includes a source of pressurized liquid capable of providing a feed flow of the liquid, or a recirculating flow of a liquid, or an overpressure flow of the liquid, or combinations thereof. The system also includes a first flow sensor for receiving the feed flow of the liquid, a second flow sensor for receiving the recirculating flow of the liquid, and a third flow sensor for receiving the overpressure flow of the liquid. Each of the first, second and third flow sensors

include a flow tube having a float located in the flow tube and configured for liquid flowing in the flow tube to flow around the float. Each float includes a magnet.

[0009] The system also includes an electronic circuit. The electronic circuit includes (i) a first magnetic sensor located proximate the first flow sensor for sensing a position of the magnet in the float of the first flow sensor, wherein the position of the magnet in the flow tube of the first flow sensor is related to flow characteristics associated with the feed flow of the liquid through the first flow sensor, (ii) a second magnetic sensor located proximate the second flow sensor for sensing a position of the magnet in the float of the second flow sensor, wherein the position of the magnet in the flow tube of the second flow sensor is related to flow characteristics associated with the recirculating flow of the liquid through the second flow sensor, and (iii) a third flow sensor for sensing a position of the magnet in the float of the third flow sensor, wherein the position of the magnet in the flow tube of the third flow sensor is related to flow characteristics associated with the overpressure flow of the liquid through the third flow sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Further advantages of the disclosure are apparent by reference to the detailed description when considered in conjunction with the figures, which are not to scale so as to more clearly show the details, wherein like reference numbers indicate like elements throughout the several views, and wherein:

[0011] FIG. 1 is a perspective view showing a catalyst flow sensor according to the disclosure.

[0012] FIG. 2 is a cross-sectional view of a catalyst flow sensor array according to the disclosure.

[0013] FIG. 3 shows a front panel of the catalyst flow sensor array of FIG. 2.

[0014] FIGS. 4-6 are interior views of the catalyst flow sensor array of FIG. 2.

[0015] FIGS. 7A-7C show dimensions of components of the catalyst flow sensor array of FIG. 2.

[0016] FIG. 8A is a perspective view of a float component of the catalyst flow sensor array of FIG. 2.

[0017] FIGS. 8B and 8C show dimensions of the float component.

[0018] FIG. 9 is a perspective view showing additional components of the catalyst flow sensor array of FIG. 2.

[0019] FIG. 10 depicts a flow chart of alarm logic for the catalyst flow sensor array of FIG. 2.

[0020] FIG. 11 depicts an alternate flow chart of alarm logic for the catalyst flow sensor array of FIG. 2.

DETAILED DESCRIPTION

[0021] With initial reference to FIG. 1, there is shown a flow sensor **10** according to the disclosure and configured for use with liquid catalysts and designed to detect when the flow of catalyst is outside of predetermined parameters. An example catalyst is a water-soluble organic peroxide known as methyl ethyl ketone peroxide (MEKP). MEKP has a viscosity at 20 degrees C of 31 mPas.

[0022] The flow sensor **10** and the devices described herein that incorporate such flow sensors are desirable for use on the supply line of a catalyst to be mixed with a resin via a spray applicator for short-fiber composite manufacturing processes. In these processes, the resin and the catalyst are mixed just before application/spraying and it is important to maintain the flows in desired amounts. The present disclosure relates to monitoring of the flow of the catalyst, which is typically supplied at a pressure of about 1,500 psi.

[0023] The flow sensor **10** includes a catalyst flow tube **12** formed as by machining the flow tube **12** through a block of metal such as stainless steel. Catalyst flows through the flow tube **12** in the direction of arrow **A** from a source of catalyst toward a spray gun, nozzle or other applicator device. For example, a catalyst pump provides a pressurized flow of catalyst via tubing into an entrance end **12a** of the flow tube **12** for exit via tubing connected to an exit end

12b of the flow tube to a spray nozzle or applicator device. Typically, mixing of resin and catalyst occurs within the spray nozzle or applicator device.

[0024] A float **14** having a magnet **16** embedded therein is located within the catalyst flow tube **12**. The float **14** is desirably cylindrical and sized smaller than the catalyst flow tube **12** to provide a fluid gap **18** between the float **14** and the interior sidewall of the catalyst flow tube **12**.

[0025] The flow sensor **10** includes an enclosure (not shown), desirably of metal and attached to the block of metal through which the flow tube **12** is machined, for housing an electrical control circuit such as a circuit having a microcontroller **22** and a giant magnetoresistance (GMR) sensor **24** located in proximity to the magnet **16** so as to be able to detect the location of the magnet **16** in the float **14** in the catalyst flow tube **12**. The enclosure serves to protect the internal circuitry from the potentially reactive environment associated with resin/catalyst spray operations.

[0026] The GMR sensor **24** is a multilayer sensor having alternating ferromagnetic and non-magnetic conductive layers. In broad overview, the sensor **24** detects the magnetic field of the magnet **16**, and detects changes in the magnetic field corresponding to changes in position of the magnet **16**.

[0027] When the flow sensor **10** is in use to detect the flow of catalyst, the float **14** will rise if the minimum flow rate of the catalyst is such that the forces generated in the fluid gap caused by the shearing of the fluid between the float **14** and the flow tube **12** are sufficient to overcome the combined weight of the float **14** and the magnet **16** embedded in the float **14**. Thus, the position of the float **14** will vary based on the flow rate of the catalyst. The sensor **24** detects the position of the float **14** in the flow tube **12** and generates output signals corresponding to the detected position of the float **14**.

[0028] The float **14** will be located in a desired range of positions if the flow rate of the catalyst is within a desired range. In the event the position of the float **14** is detected by the sensor **24**

to be outside of the desired range of positions, the microcontroller 22 may cause the generation of an alarm signal, such as an audible or visual alarm or both.

[0029] The geometry and dimensions of the float 14 are selected relative to the viscosity and the flow rates expected for the catalyst, and relative to the geometry of the flow tube 12. The float 14 cooperates with the flow tube 12 and the flow of the catalyst to be in a desired range of positions for desired flow rates of a particular catalyst through the flow tube 12.

[0030] The flow sensor 10 advantageously utilizes magnetic fields and fluid shear forces of the catalyst to indicate when desired minimum flow of the catalyst is achieved. The sensor 10 also advantageously avoids the use of seals and rotating parts that are prone to corrosion and/or failure when exposed to reactive catalyst fluids.

[0031] In a preferred embodiment, as shown in connection with FIGS. 2-9, a flow sensor array **30** incorporates a plurality of flow sensors **30a**, **30b** and **30c** to provide a catalyst flow monitoring and alert system according to the disclosure preferably having visual and audible alerts. The flow sensors 30a, 30b, and 30c each substantially correspond to the flow sensor 10 and include a catalyst flow tube **32** through which catalyst flows in the direction of the arrow A, and a float **34** having a magnet **36** embedded therein. The flow tubes 32 may be formed by machining the flow tubes 32 through a block of metal **38** such as stainless steel.

[0032] Flow sensors 30a-30c are used for sensing different aspects of catalyst flow for the array 30. For example, the flow sensor 30a is utilized to determine if the catalyst is flowing at least a desired minimum rate. The flow sensor 30b is utilized to determine if catalyst is flowing out a bypass valve of the array 30, which indicates that the catalyst is not being mixed with the resin. The flow sensor 30c is utilized to determine if catalyst is flowing out of an over-pressure outlet, which indicates that only a partial amount of the required catalyst is being mixed with the resin.

[0033] The flow sensor array 30 includes an enclosure **40**, desirably of metal, that is bolted to the block of metal 38 through which the flow tubes 32 are machined. The enclosure 40 includes an electrical control circuit such as a circuit board **42** having a microcontroller **42a** including

a plurality of giant magnetoresistance (GMR) sensors **44**, one located in proximity to each of the magnets **36** so as to be able to detect the location of the floats **34** having the magnets **36** in the catalyst flow tubes **32** of the flow sensors **30a-30c**. The microcontroller **42** with the sensors **44** function to read the positions of the floats **34** of the flow sensors **30a-30c** and alert an operator if any noteworthy states, such as fail states exist in any of the flow sensors **30a-30c** and, if so, in which flow sensor the fail state has occurred.

[0034] As shown in FIG. 9, the catalyst is supplied from a source of catalyst by a catalyst pump **50** or the like to provide a pressurized flow of catalyst. The catalyst is fed initially to a manifold **52** having a supply outlet **54a**, a recirculation outlet **54b**, and an overpressure outlet **54c**. These manifold outlets **54a-54c** are connected via tubing **56a**, **56b**, and **56c**, respectively, to input connectors of the flow sensors **30a-30c**, respectively, for travel of catalyst to the array **30**, and through the flow sensors **30a-30c**.

[0035] Catalyst exiting the flow sensor **30a** is routed via tubing to the spray gun, nozzle or other applicator device for mixing with the resin for application. The applicator device is typically pneumatic and exhausts air during operation. As described in more detail below, the exhaust air of the applicator device is harnessed and routed to an applicator air input **58** of the array **30** to be used to indicate to the array **30** when a spraying operation is being conducted.

[0036] During a spraying operation, the float **34** of the flow sensor **30a** will rise if the minimum flow rate of the catalyst through the flow sensor **30a** is such that the forces generated in the fluid gap caused by the shearing of the fluid between the float **34** and the flow tube **32** are sufficient to overcome the combined weight of the float **34** and the magnet **36** embedded in the float **34**. The associated sensor **44** detects the position of the float **34** in the flow tube **32** of the flow sensor **30a** and generates output signals corresponding to the detected position of the float **44**. Likewise, if catalyst flows from the recirculation outlet **54b** to the flow sensor **30b** and/or catalyst flows from the overpressure outlet **54c** to the flow sensor **30c**, these flows of catalyst will act on the floats **34** of the flow sensors **30b** and **30c** and be detected by the associated sensors **44** in a similar manner.

[0037] As noted above, the geometry and dimensions of the floats 34 are selected relative to the viscosity and the flow rates expected for the catalyst, and for the geometry of the flow tubes 13 so as to cooperate to enable the floats 34 to be in a desired range of positions for desired flow rates of a particular catalyst. A preferred catalyst is MEKP having a viscosity of 31 mPas at 20 degrees C. The flow rate of the catalyst preferably ranges from about 0.65 fluid ounces per minute to about 19 fluid ounces per minute with a minimum flow rate of about 0.5 fluid ounces per minute.

[0038] With reference to FIGS. 7A-7C, the catalyst flow tubes 32 of the flow sensors 30a-30c are desirably arranged and dimensioned as shown for use with the described catalyst.

[0039] With reference to FIGS. 8A-8C, the floats 34 and the magnets 36 of the flow sensors 30a-30c are configured as shown for use with the described catalyst and flow tubes 32. The floats 34 preferably include a slot **34a** on the bottom thereof and a top **34b** that is flat with rounded edges. The slot 34a advantageously enables catalyst fluid to flow in the opposite direction and prevents the float 34 from sealing against a lip in the flow tube 32. The top 34b advantageously reduces frictional flow coefficients of the float 34.

[0040] The floats 34 are desirably made of 316 grade stainless steel with a weight of about 1.8 grams. The magnets 36 are preferably cylindrical and characteristics of a desirable magnet for use in providing the magnets 36 are set forth in Table 1 below:

[0041] Table 1

Dimensions:	1/8 inch diameter by 1/2 inch thick
Tolerances	+/- 0.004 inch x +/- 0.004 inch
Material	NdFeb, grade N52
Plating/Coating	Ni-Cu-Ni (Nickel)
Magnetization Direction	Axial (Poles on Flat Ends)
Weight	0.0266 ounces (0.754 grams)
Pull Force, Case 1	1.08 pounds
Pull Force, Case 2	1.09 pounds
Surface Field	7343 Gauss
Max Operating Temperature	176°F (80°C)
Brmax	14,800 Gauss
Bhmax	52 MGOe

[0042] To power the circuit board 42, electrical power, preferably 12-volt direct current, may be supplied to the flow sensor array 30 via a power input **60** in electrical communication with a power supply, generally indicated with reference numeral **62** (FIG. 9). The power supply 62 is preferably provided by a 110-volt alternating current to 12-volt direct current power supply integrated into a cord that may be plugged into an electrical outlet, preferably 110-220 VAC 50-60 Hz. Electrical power is connected from the power supply 62 to the circuit board 42 via a power input terminal **64** on the circuit board 42 (FIG. 4). When electrical power is supplied to the circuit board 42, a power indicator lamp **66** is desirably illuminated to indicate to an operator that power has been supplied.

[0043] Lights or other visual indicators **70a**, **70b**, and **70c** are provided to indicate if an undesirable flow of catalyst is detected by any of the flow sensors 30a-30c, respectively. In this regard, indicator 70a illuminates if the array 30 is powered and the flow of catalyst as detected by the flow sensor 30a is below the desired minimum flow. Indicators 70b and 70c illuminate when flow of catalyst occurs through the flow sensor 30b and 30c, respectively as explained more fully below. The indicators 70a-70c are connected to the circuit board 42 by an indicator terminal **72** and are controlled by the microcontroller 42a in response to signals received from the flow sensors 30a-30c.

[0044] With reference to FIG. 4, an audible alarm such as a whistle **80**, which may be remote from the enclosure 40 is provided to indicate if an undesirable flow of catalyst is detected by any of the flow sensors 30a-30c, respectively. Upon hearing the alarm, the operator may look to the visual indicators to determine the cause of the alarm. The whistle 80 is air operated due to the reactive environment. Air is supplied into the array 30 via an alarm inlet air port **82a** and routed from the array via an alarm outlet air port **82b**. The alarm inlet air is routed from the port 82a to a solenoid valve **84** via conduit **86a** and from the valve 84 to the port 82b by conduit **86b**. The valve 84 is connected to the circuit board 42 by a valve terminal **88** and are controlled by the microcontroller 42a in response to signals received from the flow sensors 30a-30c. In the event the flow of catalyst as detected by the flow sensor 30a is below the desired minimum flow and/or flow of catalyst occurs through the flow sensor 30b and 30c, the valve 84 will open to supply air to the whistle 80.

[0045] The indicators 70a-70c and alarm 80 are desirably only activated when a spraying operation is being conducted. As mentioned above, exhaust air of the applicator device is harnessed and routed to the applicator air input 58 of the array 30 to be used to indicate to the array 30 when a spraying operation is being conducted. This input air is utilized by the array 30 to connect the indicators 70a-70c and the solenoid valve 84 to the circuit board 42 to arm them for use. With reference to FIG. 4, this may be accomplished as by routing the air from the air input 58 via tubing **90** to an air pressure sensor **92**. The microcontroller 42a reads pressure signals from the sensor 92. When a sufficient pre-selected air pressure corresponding to a spraying operation is sensed, the indicators 70a-70c and the solenoid valve 84 are activated. A sensitivity adjustment for adjustment of the pre-selected air pressure may be incorporated.

[0046] Fig. 10 depicts an example of flow chart of alarm logic implemented by the microcontroller 42a in operation of the flow sensor array 30. For example, in a first step **100** electrical power is supplied to the circuit board 42 and in step **102** the air pressure sensor 92 monitors any exhaust air pressure of a spraying operation. When a sufficient pre-selected air pressure corresponding to a spraying operation is detected by the air sensor 92 (step **104**) the indicators 70a-70c and the solenoid valve 84 are activated (step **106**). For example, the sensor 92 may sense sufficient air pressure if three consecutive pressure pulses are sensed.

[0047] As seen in step **108**, catalyst flow is monitored by the flow sensors 30a-30c. As will be noted, the indication of an active spraying operation requires a flow of catalyst to the sprayer/applicator. Step **110** relates to the operation of the flow sensor 30c. If catalyst flows from the overpressure outlet 54c to the flow sensor 30c this will be detected and the indicator 70c illuminated and the solenoid valve 84 activated to supply air to the whistle 80 (step **112**). The whistle 80 and the indicator 70c should alert the operator to cease the spraying operation, which results in a cessation of exhaust air to the applicator air input 58. In the event cessation of air flow is not detected, the indicator 70c remains illuminated and air continues to be supplied to the whistle 80. Once a cessation of air flow has been detected, such as for three seconds, as seen in step **114**, the microcontroller 42a will activate the solenoid valve 84 to stop air flow to the whistle 80 (step **116**). If the issue is corrected, the operator can turn off the

indicator 70c (steps **118** and **118a**) and the microcontroller 42a awaits re-activation (return to step 102). If the issue is not corrected, the spraying operation is deemed ended (step **120**). If spraying resumes, the fail state is reset.

[0048] Returning to step 110, if the flow sensor 30c does not detect an over-pressure condition, the process proceeds to step **122** which relates to operation of the flow sensor 30b. If catalyst is flowing from the recirculation outlet 54b to the flow sensor 30b this will be detected and the indicator 70b illuminated and the solenoid valve 84 activated to supply air to the whistle 80 (step **124**). The whistle 80 and the indicator 70b should alert the operator to cease the spraying operation, which results in a cessation of exhaust air to the applicator air input 58. Once a cessation of air flow has been detected, such as for three seconds, as seen in step **126**, the microcontroller 42a will activate the solenoid valve 84 to stop air flow to the whistle 80 (return to step 116). In the event cessation of air flow is not detected, the indicator 70b remains illuminated and air continues to be supplied to the whistle 80.

[0049] Returning to step 122, if the flow sensor 30b does not detect recirculation flow, the process returns to step **128**, which relates to operation of the flow sensor 30a. If the flow rate of catalyst through the sensor 30a is below the desired minimum flow, this will be detected and the indicator 70a illuminated and the solenoid valve 84 activated to supply air to the whistle 80 (step **130**). The whistle 80 and the indicator 70a should alert the operator to cease the spraying operation, which results in a cessation of exhaust air to the applicator air input 58. Once a cessation of air flow has been detected, such as for three seconds, as seen in step **132**, the microcontroller 42a will activate the solenoid valve 84 to stop air flow to the whistle 80 (return to step 116). In the event cessation of air flow is not detected, the indicator 70a remains illuminated and air continues to be supplied to the whistle 80.

[0050] Fig. 11 depicts another example of a flow chart of alarm logic implemented by the microcontroller 42a in operation of the flow sensor array 30. For example, in a first step **200** electrical power is supplied to the circuit board 42 and in step **202** the air pressure sensor 92 monitors any exhaust air pressure of a spraying operation, which exhaust air is delivered in pulses from the spray equipment.

[0051] When a first pulse of air pressure is detected by the air sensor 92 (step **204**), a measurement of the cycle rate of air pressure pulses detected by the air sensor 92 begins (step **206**). If a second pulse of air is detected (step **208**), a determination of the time between detection of the first pulse of air and the second pulse is made and compared to a predetermined time between pulses, such as 10 seconds (step **210**). If the time between pulses exceeds the predetermined time, then a disarm command is sent (step **212**) and the process returns to step 202. If the time between pulses does not exceed the predetermined time, then a time corresponding to the determined time from step 210 is set in step **214** as the cycle rate of the exhaust air pulses and the indicators 70a-70c are cleared (step **216**) and the indicators 70a-70c and the solenoid valve 84 are activated (step **218**).

[0052] Once the indicators 70a-70c and the solenoid valve 84 are activated, the cycle rate of the exhaust air pulses is monitored (step **220**) and compared (step **222**) to the rate set in step 214. If the cycle rate does not exceed the rate set in step 214, monitoring continues. If the rate exceeds the rate, the process proceeds to step 212 and a disarm command is sent. If the spraying operation continues, a new cycle rate of the exhaust air pulses may be periodically set based on the continuing operation of the spraying equipment (steps **222a** and **222b**).

[0053] In addition, the flow sensors 30a-30c are monitored in step **224**. The decision tree first looks to overpressure flow, then recirculation flow, and then feed flow in order to sound the alerts, but undesired flow sensed by any of the flow sensors 30a-30c will trigger the alerts. In step **226**, if catalyst flows from the overpressure outlet 54c to the flow sensor 30c this will be detected and the indicator 70c is illuminated and the solenoid valve 84 activated to supply air to the whistle 80 (step **228**). As shown in steps **230** and **232**, the whistle 80 is activated for a desired time period, such as 2 seconds, and then turned off.

[0054] In step **234**, if catalyst flows from the recirculation outlet 54b to the flow sensor 30b, this will be detected and the indicator 70c is illuminated and the solenoid valve 84 is activated to supply air to the whistle 80 (step **236**). As shown in steps **238** and **240**, the whistle 80 is activated for a desired time period, such as 2 seconds, and then turned off.

[0055] In step **242**, if catalyst flows from the supply outlet 54a through the sensor 30a and this flow rate is at or above the desired minimum flow, the process returns to step 224. If the flow rate is below the desired minimum flow, this condition represents an interrupted flow of the catalyst. In such case, the degree of interruption is calculated in step **244** and compared to a set point, such as between 0 and 400 ms (step **246**). If the interruption is less than the set point, the process returns to step 224. If the interruption is greater than the set point, in step 248 the number of interrupts is determined and then compared in step **250** to a predetermined interrupt number, such as 2. If the number of interrupts is at or less than the predetermined interrupt number, the process returns to step 224. If the number of interrupts is greater than the predetermined interrupt number, in step **252** a signal is generated indicating that catalyst flow has been interrupted and in step **254** the indicator 70a is illuminated and the solenoid valve 84 activated to supply air to the whistle 80. As shown in steps **256** and **258**, the whistle 80 is activated for a desired time period, such as 2 seconds, and then turned off.

[0056] As will be appreciated, the present disclosure advantageously provides flow sensors that enable flow detection utilizing magnetic fields to detect the position of a magnet housed in a float that is affected by fluid flow. Such sensors have been observed to be particularly suitable for use in determining and monitoring the flow of highly reactive catalysts for which conventional flow sensors are unsuited.

[0057] Further, the disclosure incorporates such flow sensors to provide systems configured for use with catalysts to detect when the flow rate of the catalyst is outside of a desired range, and to alert operators when undesirable flow conditions occur.

[0058] The systems employ the use a microcontroller to read the position of floats in a flow sensor array then to alert the operator if any fail-states exists and which one it is. Additionally, the system advantageously does not require any operator input or calibration and can sense when a spraying operation is active and activate the alerts only during that time.

[0059] The foregoing description of preferred embodiments for this invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise form disclosed. Obvious modifications or variations are

possible in light of the above teachings. The embodiments are chosen and described in an effort to provide the best illustrations of the principles of the invention and its practical application, and to thereby enable one of ordinary skill in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the invention.

CLAIMS

1. A liquid flow sensor, comprising:

an elongate flow tube having an inlet end and an outlet end, wherein a liquid flows into the flow tube at the inlet end and exits from the outlet end;

a float located in the flow tube and configured for the liquid flowing in the flow tube to flow around the float, the float including a magnet; and

an electrical circuit proximate the flow tube, the electrical circuit including a magnetic sensor located proximate the float for sensing a position of the magnet in the flow tube, wherein the position of the magnet in the flow tube is related to the position of the float in the flow tube, which is related to flow characteristics associated with flow of the liquid through the flow tube.

2. The flow sensor of claim 1, wherein the liquid comprises a catalyst liquid.

3. The flow sensor of claim 2, wherein the catalyst liquid comprises methyl ethyl ketone peroxide.

4. The flow sensor of claim 1, wherein the magnetic sensor comprises a giant magnetoresistance sensor.

5. The flow sensor of claim 1, further comprising an alarm that is activated by the electrical circuit in response to a signal generated by the magnetic sensor based on a flow characteristic of the flow of liquid.

6. The flow sensor of claim 1, wherein the float rises in the flow tube if the flow of the liquid meets or exceeds a predetermined minimum flow rate of the liquid.

7. A method of monitoring flow of a liquid, comprising the steps of:

flowing a liquid under pressure through an elongate flow tube having an inlet end and an outlet end, wherein the liquid flows into the flow tube at the inlet end and exits at the outlet end;

providing a float including a magnet in the flow tube, the float configured so that the liquid flowing in the flow tube flows around the float;

directing the flow of liquid through the elongate flow tube to contact and flow around the float such that the position of the float in the flow tube is dependent upon the flow of liquid through the flow tube; and

sensing a position of the magnet in the flow tube, wherein the position of the magnet in the flow tube is related to the position of the float in the flow tube, which is related to flow characteristics associated with flow of the liquid through the flow tube.

8. The method of claim 7, further comprising the step of activating an audible alert if the flow of liquid is below a predetermined minimum flow rate.

9. The method of claim 8, wherein prior to activation of the audible alert, the flow of the liquid must first be at or above the predetermined flow rate.

10. The method of claim 7, wherein the liquid comprises a catalyst liquid.

11. The method of claim 10, wherein the catalyst liquid comprises methyl ethyl ketone peroxide.

12. The method of claim 7, wherein the sensing of the position of the magnet is performed by a giant magnetoresistance sensor.

13. The method of claim 7, further comprising a visual alert that is activated if flow of the liquid is detected to be below a predetermined minimum flow rate.

14. A flow monitoring system, comprising:

a source of pressurized liquid capable of providing a feed flow of the liquid, or a recirculating flow of a liquid, or an overpressure flow of the liquid, or combinations thereof;

a first flow sensor for receiving the feed flow of the liquid,

a second flow sensor for receiving the recirculating flow of the liquid, and

a third flow sensor for receiving the overpressure flow of the liquid,

each of the first, second and third flow sensors comprising a flow tube having a float located in the flow tube and configured for liquid flowing in the flow tube to flow around the float, each float including a magnet; and

an electronic circuit including:

(i) a first magnetic sensor located proximate the first flow sensor for sensing a position of the magnet in the float of the first flow sensor, wherein the position of the magnet in the flow tube of the first flow sensor is related to flow characteristics associated with the feed flow of the liquid through the first flow sensor,

(ii) a second magnetic sensor located proximate the second flow sensor for sensing a position of the magnet in the float of the second flow sensor, wherein the position of the magnet in the flow tube of the second flow sensor is related to flow characteristics associated with the recirculating flow of the liquid through the second flow sensor, and

(iii) a third flow sensor for sensing a position of the magnet in the float of the third flow sensor, wherein the position of the magnet in the flow tube of the third flow sensor is related to flow characteristics associated with the overpressure flow of the liquid through the third flow sensor.

15. The system of claim 14, further comprising an audible alert that is activated by the electronic circuit, wherein the alert is activated if the first flow sensor detects flow of the feed flow below a predetermined minimum flow rate, or the second flow sensor detects flow of the recirculating flow, or if the third flow sensor detects flow of the overpressure flow.

16. The system of claim 15, wherein prior to activation of the audible alert, the flow of the feed flow must first be at or above the predetermined flow rate.

17. The system of claim 14, wherein the liquid comprises a catalyst liquid.

18. The system of claim 17, wherein the catalyst liquid comprises methyl ethyl ketone peroxide.

19. The system of claim 14, wherein the first, second, and third magnetic sensors each comprise a giant magnetoresistance sensor.

20. The system of claim 14, further comprising a first visual alert that is activated if the first flow sensor detects flow of the feed flow below a predetermined minimum flow rate, a second visual alert that is activated if the second flow sensor detects flow of the recirculating flow, and a third visual alert that is activated if the third flow sensor detects flow of the overpressure flow.

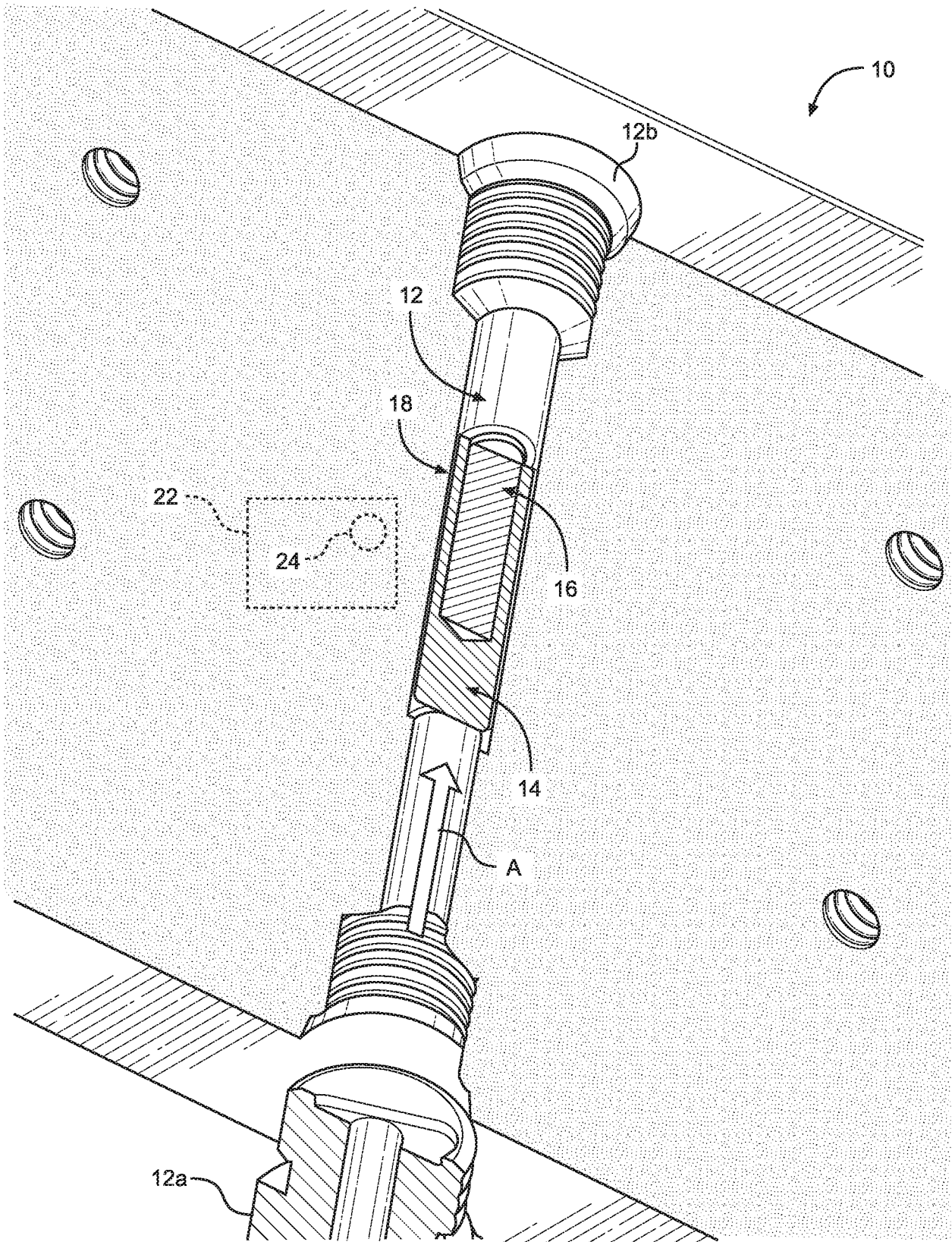
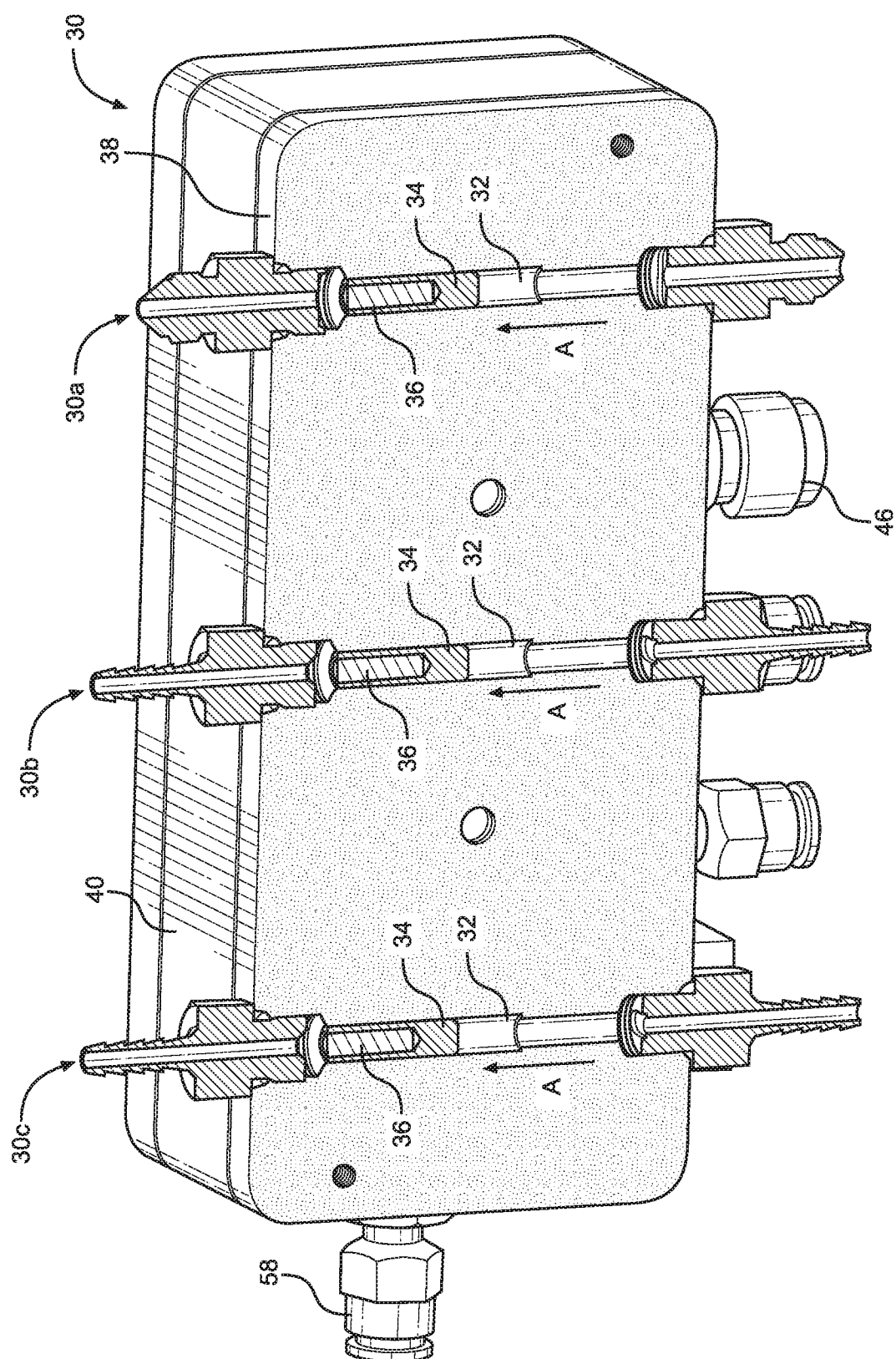
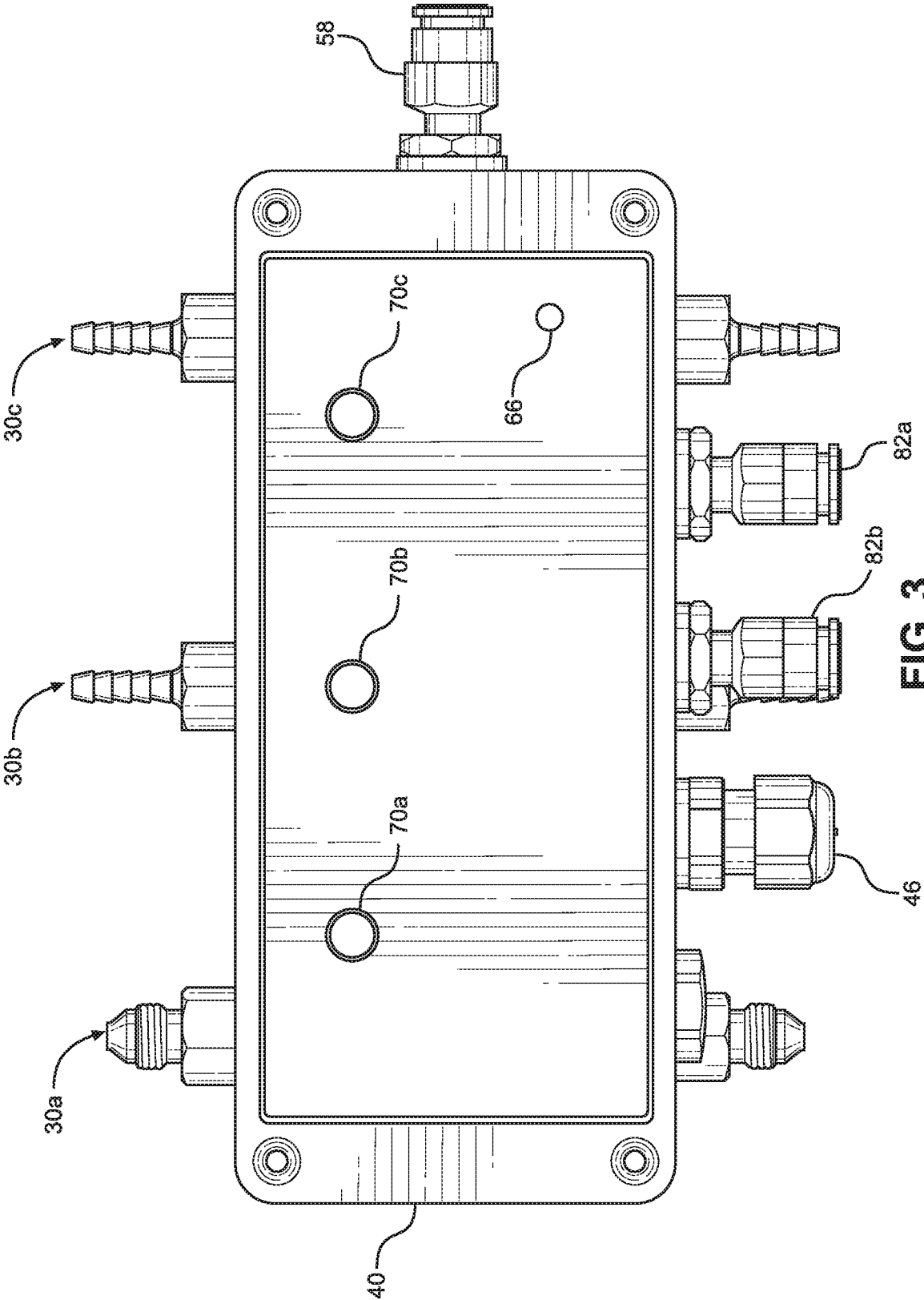


FIG. 1



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L



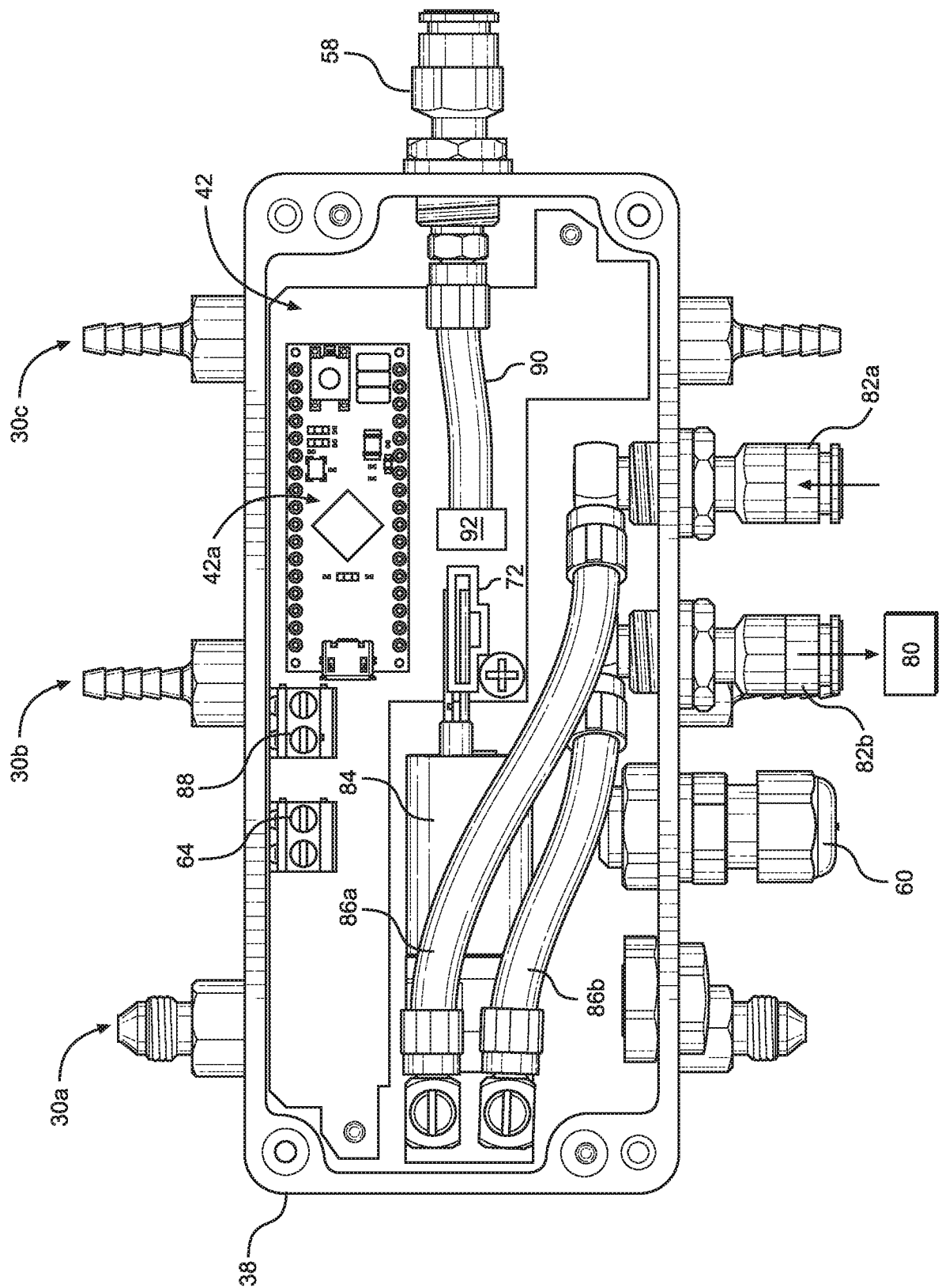


FIG. 4

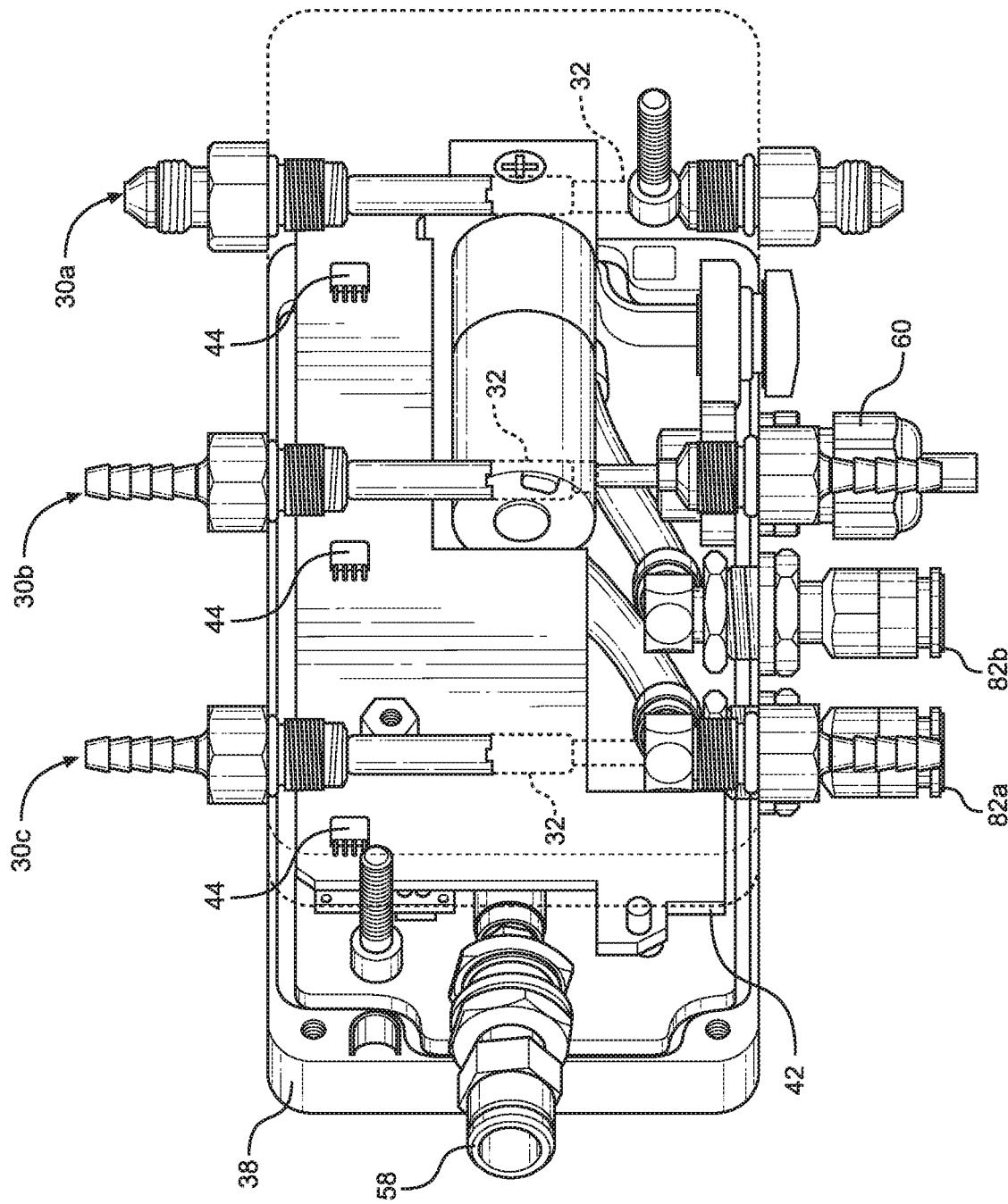


FIG. 5

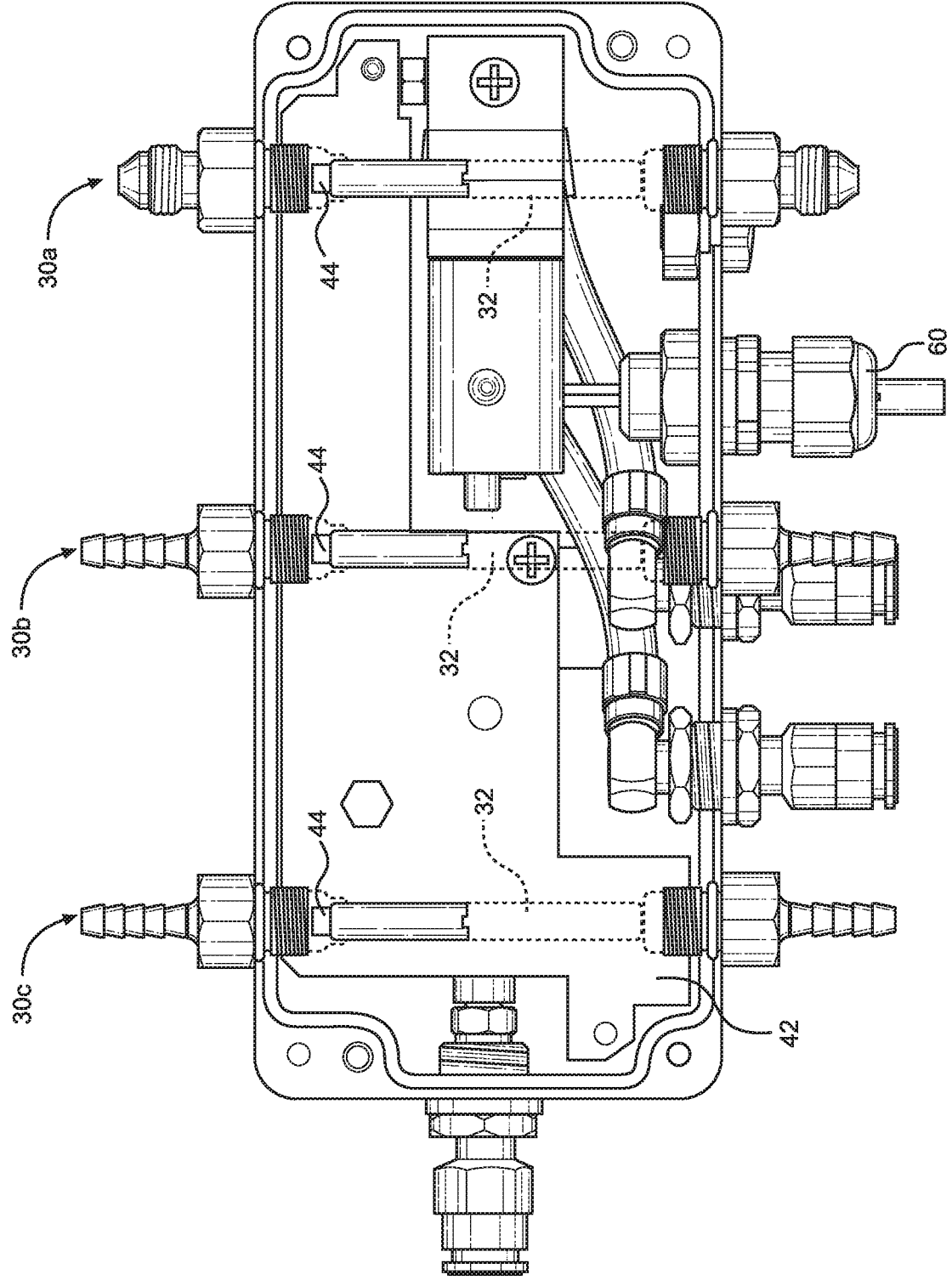


FIG. 6

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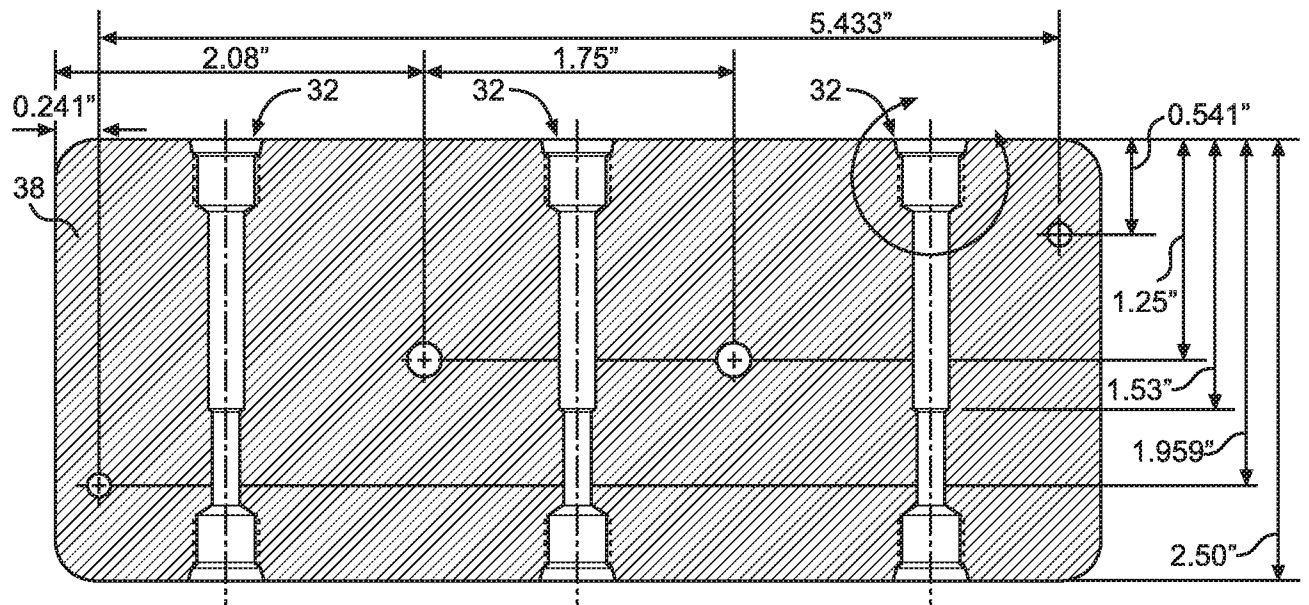


FIG. 7A

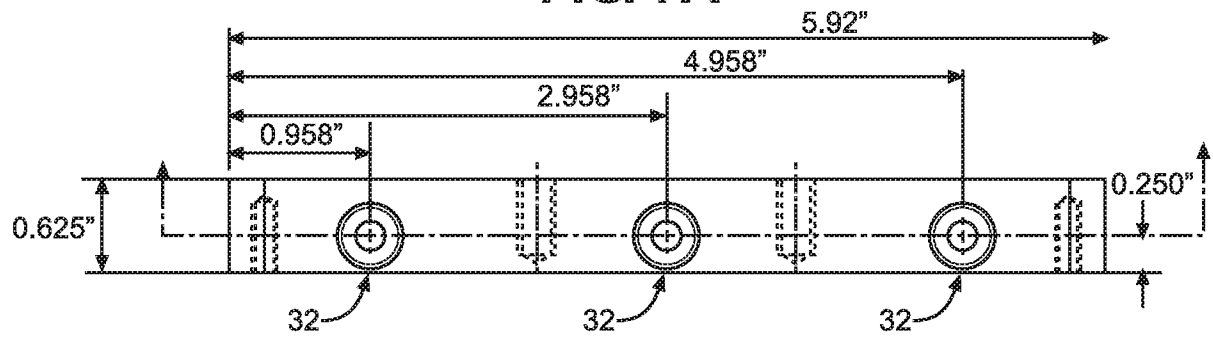


FIG. 7B

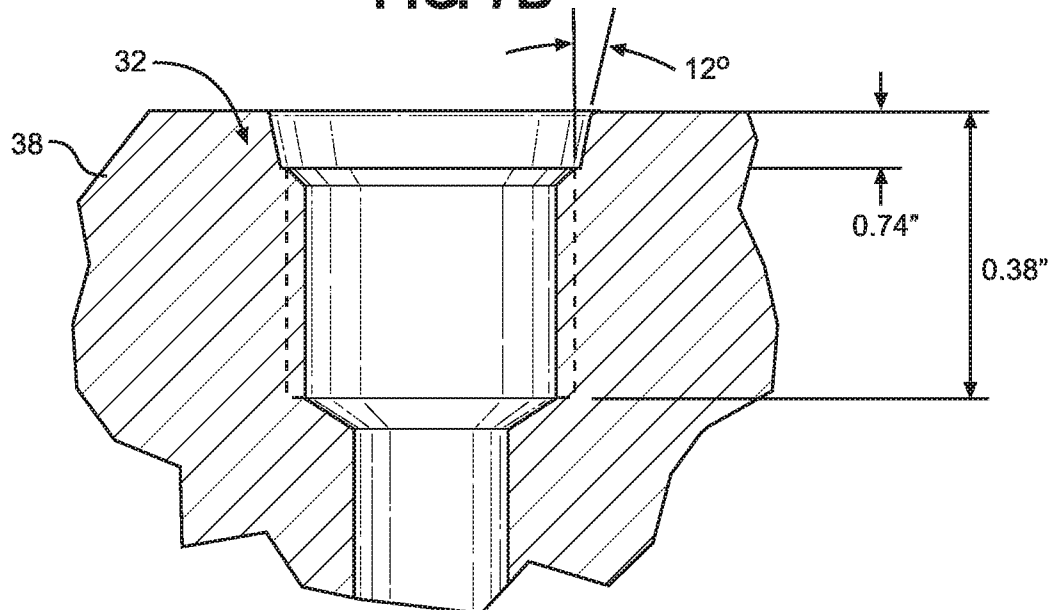


FIG. 7C

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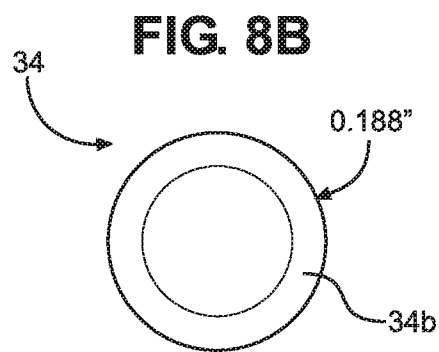
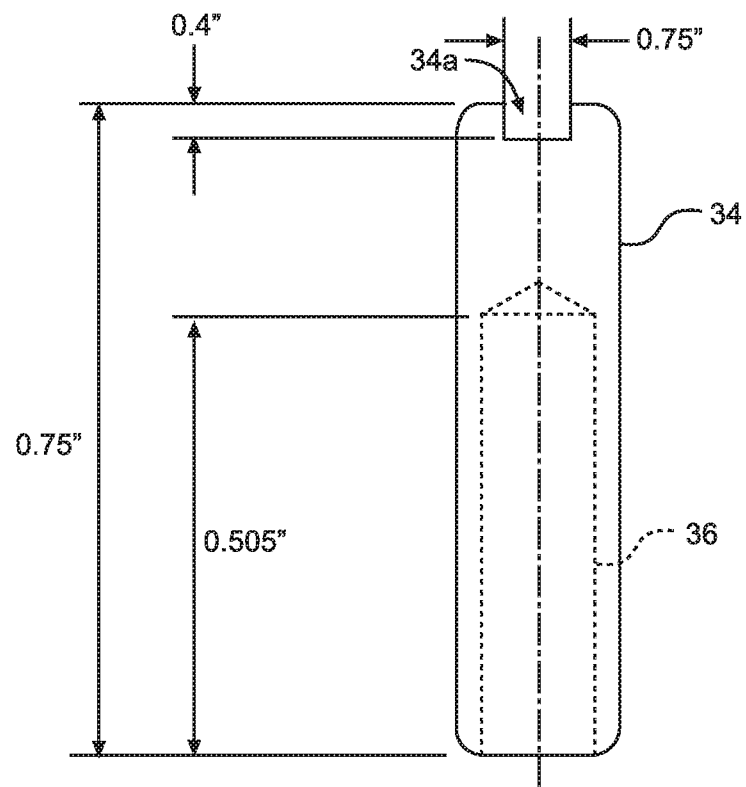
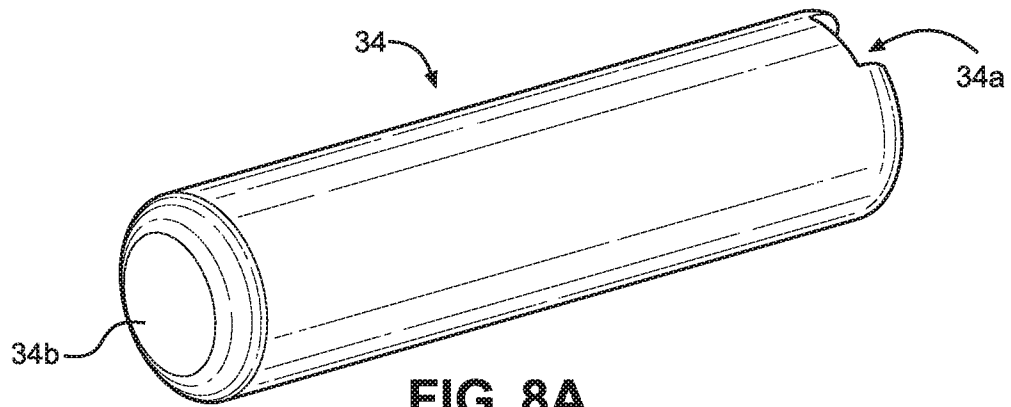
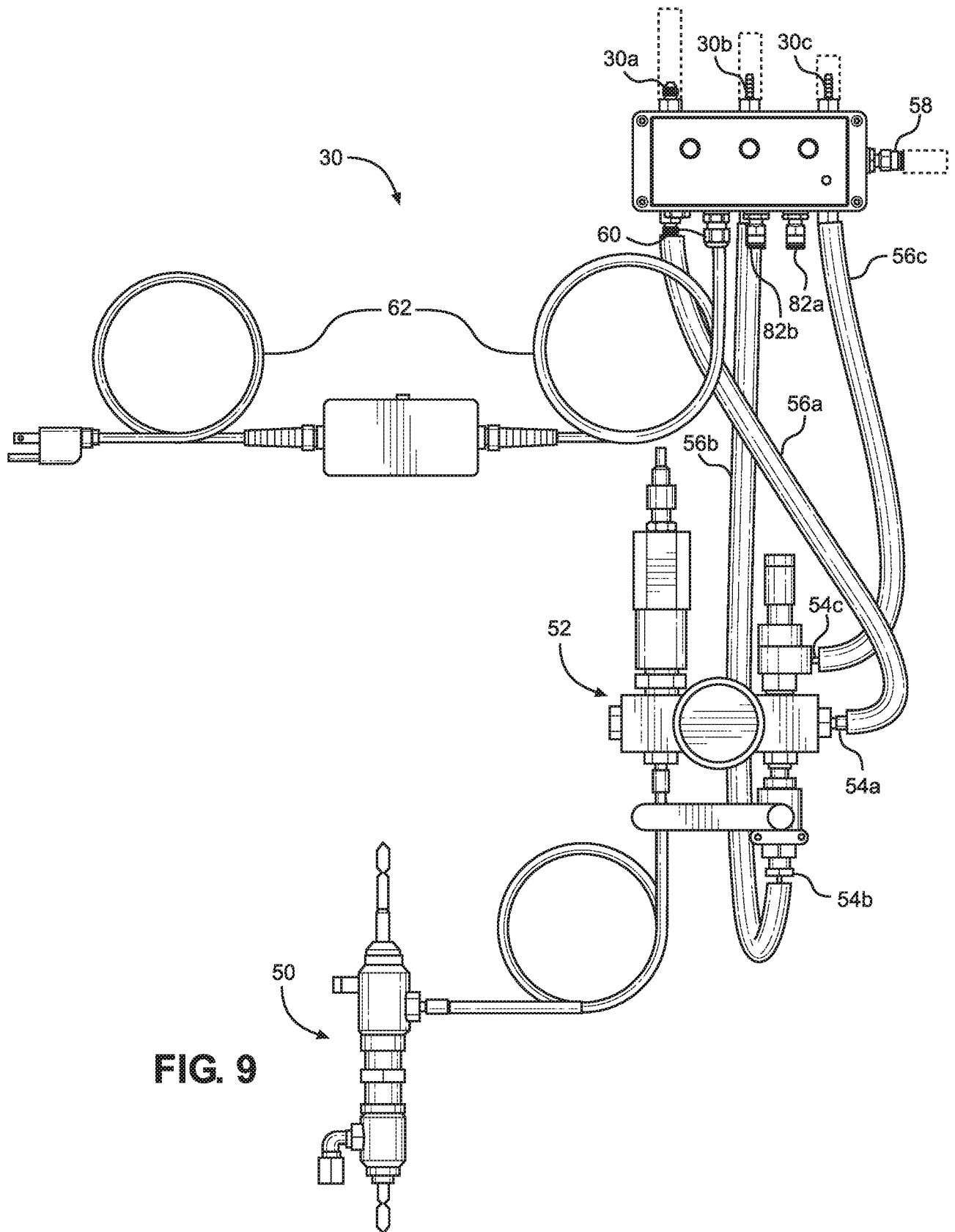
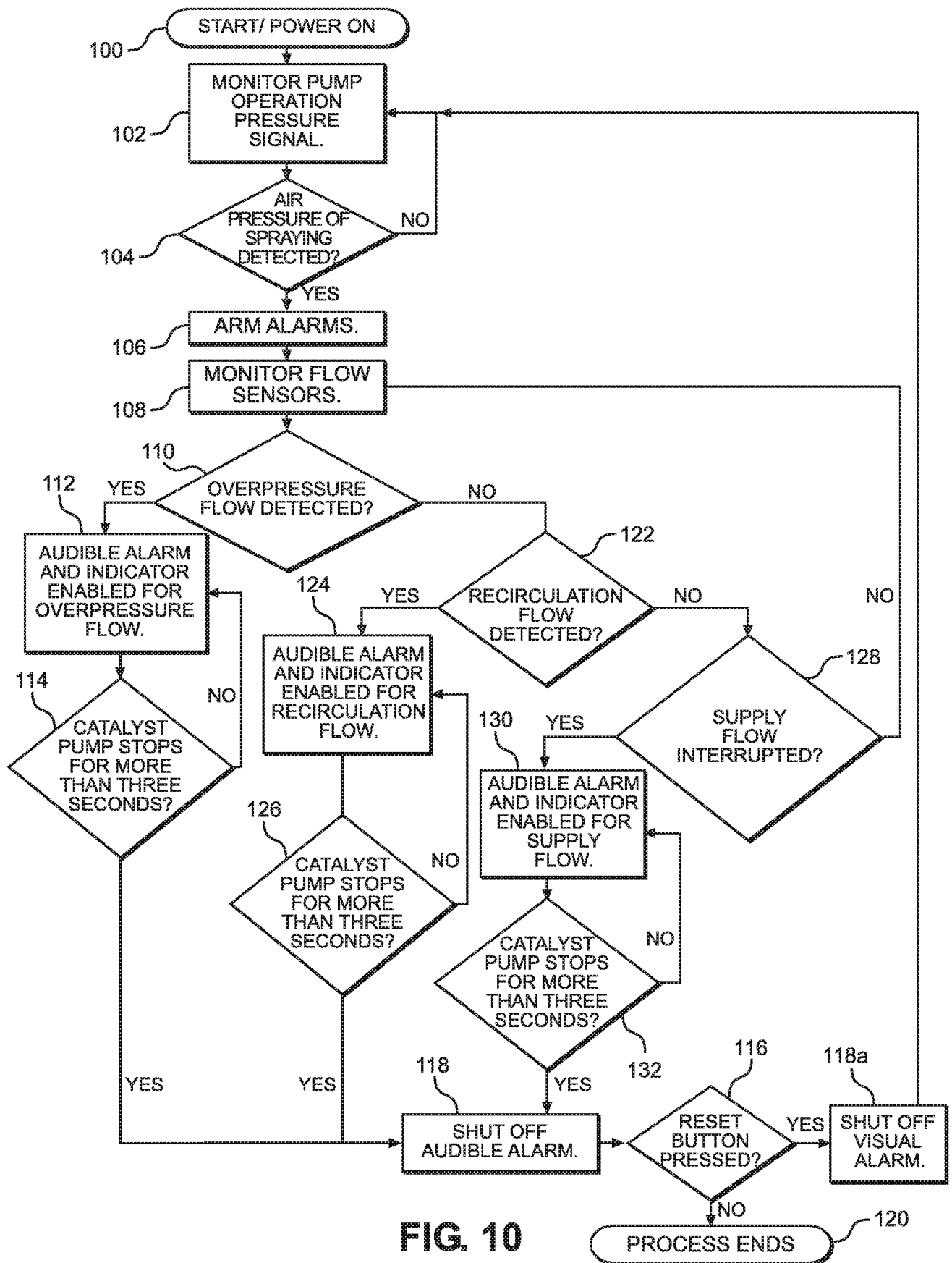


FIG. 8C



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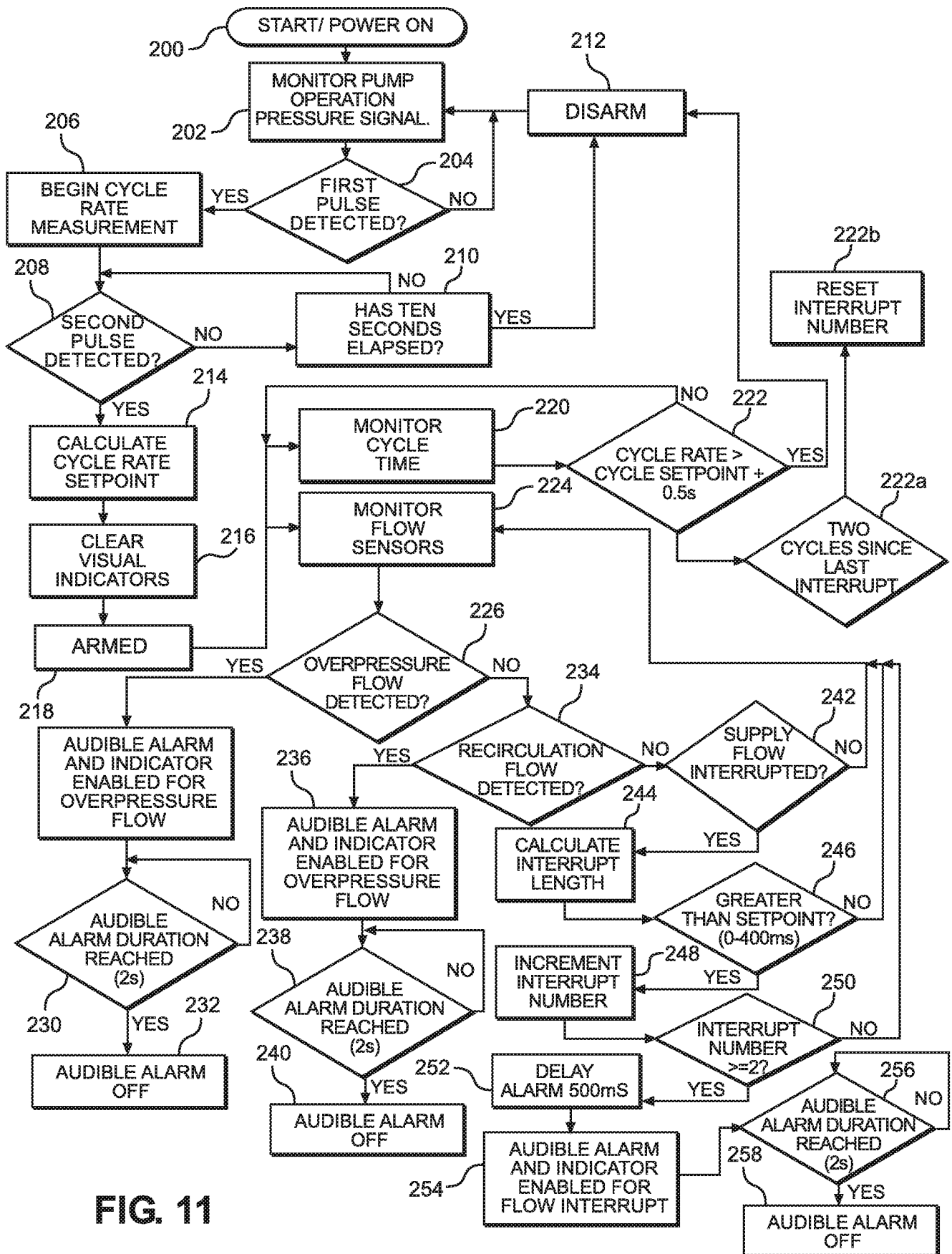


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2018/056414

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01F 1/28; G01F 1/22; G01F 1/56; G01F 1/58; G01F 3/08 (2018.01)

CPC - G01F 1/28; G01F 1/56; G01F 1/58; G01F 3/08; G01F 3/36 (2018.08)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

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

USPC - 73/239; 73/861.02; 73/861.08; 73/861.57 (keyword delimited)

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

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/0199388 A1 (FURKERT et al) 30 August 2007 (30.08.2007) entire document	1-3, 6, 7, 10, 11
Y		4, 5, 8, 9, 12-20
Y	US 7,942,070 B2 (ERTLER) 17 May 2011 (17.05.2011) entire document	4, 12, 14-20
Y	US 2004/0226388 A1 (RIEGEL) 18 November 2004 (18.11.2004) entire document	5, 8, 9, 13, 15, 16, 20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

27 November 2018

Date of mailing of the international search report

23 JAN 2019

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